Misorientation of Blocks and Crystalline Solids Resistance to Fracture

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For the problem of strength of great importance is the study of the influence of the structural elements common for a wide range of materials on the resistance to fracture. Polycrystalline solids as well as single crystals with metallic, ionic and covalent types of interatomic bonds are characterized by the formation of mosaic structure in the process of loading. This structure is a nonuniform distribution of dislocations in the medium. The maximum dislocation density occurs in the sub-boundaries and determines their misorientation.

In the present work an attempt was made to study the influence of block misorientation on the resistance of crystalline solids to fracture. The experiments were carried out on pure polycrystals (Al, Zn, Ni, Cu, Mg, Ag) and single crystals (NaCl, Ge).

1.Mechanical test. To evaluate the resistance of crystalline solids to fracture the dependence of the rupture time (lifetime τ) on the applied stress (σ) and test temperature (T) was studied. The lifetime was measured for the uniaxial tension at constant stress, i.e., under creep conditions. The experiments were carried out within a wide range of T and σ ; the relationship between τ , T and σ being described here by an equation common for all the solids (1,2)

$$\tau = \tau_0 \exp\left(\frac{U_0 - \gamma\sigma}{kT}\right) \qquad (1)$$

where k is the Boltzmann constant; τ_0, U_0, γ are the constant coefficients. Only γ is the function of the material structure. Different initial structures were formed by varying the regimes of thermal and mechanical treatment of the specimens or by changing their crystallographic orientation (for single crystals). For every material several sets of samples each set having its own initial structure were prerared, For the samples of every set the dependence of lifetime on stress and temperature was obtained which enabled us to determine the range of σ and T within which eq.(1) holds and the coefficients τ_0, U_0, γ. As an example Fig.1 and 2 show the plot of τ vs. σ and T for some materials. The coefficients of eq.(1) for these materials are listed in Table 1. It gives also the values of the rupture stress (σ^*) at fixed test temperatures (18°C for Al and 400°C for NaCl) and lifetimes ($\lg\tau = 1$). It is easily seen that $\sigma^* \sim \gamma^{-1}$. (From eq.(1) it follows that $\sigma = (U_0 - kT\ln \tau/\tau_0)\gamma^{-1}$. As τ_0 and U_0 are constant and τ, T are fixed we obtain: $\sigma = \mathrm{const}\,\gamma^{-1}$).

2. Results of structure investigations. Misorientation of blocks in the specimens was studied during the longevity test by the small-angle X-ray scattering method [3] (polycrystals) and by the analysis of the Kossel lines [4,5] (single crystals). For both methods the accuracy of measurement of block misorientation (θ) was of 10-15 percent. The control has shown that θ measured by these methods is determined by the dislocation spacing in blocks (ℓ), i.e., $\theta = \bar{b}/\ell$ where $\bar{b}$ is the Burgers vector. ℓ was determined by the transmission electron microscopy for the samples the misorientation of which had been earlier estimated by X-ray analysis. For example the value of θ obtained both by X-ray analysis and electron microscopy was 42′ and 46′ (Al) [6] and 23′ and 20′ (Ge) [5], respectively.

The structure investigations have shown that for all the investigated materials θ in the longevity test varies

in accordance with the same regularities. The interrelation between θ and ℓ being taken into account these regulariries can be formulated as follows: a.The formation of dislocation structure (refinement of blocks and the increase of their misorientation) ends as the steady-state creep incepts. At steady-state creep which contributed to the total lifetime 85-90 percent in our experiments the average density of dislocations in sub-boundaries ($N \sim \theta$) did not change until the rupture of the specimen occured; b.N is independent of the test conditions (σ, T) and is only determined by the material initial state.

3.The coefficient γ in eq.(1) is also independent of the experimental conditions. It is determined by the matarial initial state only.

Thus for single crystals as well as for polycrystalline solids with metallic, ionic and covalent types of interatomic bonds there is a close connection between γ which is inversely proportional to the rupture stress σ^* and the misorientation of blocks. The resistance to fracture is a linear function of the block misorientation, i.e., of the dislocation density in blocks N (Fig.3) [7,8].

The resistance to fracture as a function of the misorientation of blocks is described by the equation $\sigma^* \sim 1/\gamma = A\theta$ The coefficient A varies from one material to another and is constant for every material. The correlation between A and the Young's modulus (E) for the corresponding materials is observed: the larger is E, the larger is A, i.e., the dependence of the resistance to fracture on the misorientation of blocks is more pronounced.

4.To analyse the nature of the established dependence mention should be made that according to [1,2] the coefficient γ has the significance of the time-mean value of the local overstresses in the loaded solids. γ may be expressed as the product of the activation volume (close to the atomic one) and the coefficient γ'. The coefficient γ' which is equal to $\approx 10-10^2$ for crystalline solids is according to [1,2] the characteristic of local overstresses.

As the increase of N results in the reduction of $\gamma(\gamma')$ it may be believed that the formation of block boundaries (i.e., the motion of dislocations forming the boundaries) is a relaxation process which leads to the decrease of the average value of local overstresses near the block boundaries. (For instance, the blunting of the tips of microcracks which are likely to arise at initial creep) [2]. It seems to us that it is this process which leads to deceleration of fracture and to the increase of the rupture strength.

References

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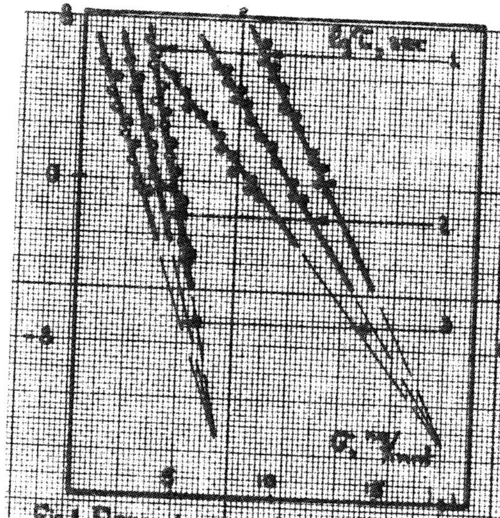

Fig.1 Dependence of lifetime of Al (annealed a–at 600°C, 1 hour; б–at 150 °C, 1 hour) upon stress. Test temperatures: 1–18, 2–100, 3–200°C

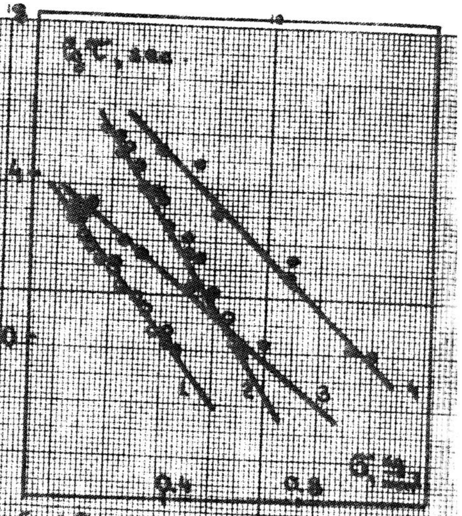

Fig.2 Dependence of lifetime of NaCl tensile specimens (tension along the planes (100)–1,2 ; (110)–3,4) upon stress. Test temperatures: 2,4–400 ; 1,3–560°C

τ_0 sec^{-1}	Material	U_0 kcal/mole	Initial state	γ cm³ (10^{-23})	σ^* kg/mm²	θ min
10^{-13}	Al (99,99%)	51	Annealing at 600°C	498	4.5	29±3
			Annealing at 150°C	193	11.6	75±8
	NaCl	65	tension along the (100)	2880	0.36	20±2
			tension along the (110)	1770	0.85	38±3

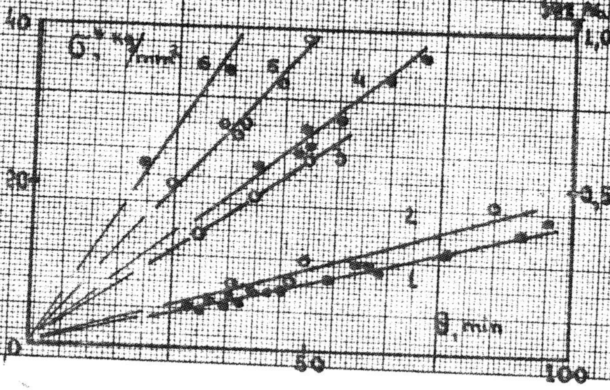

Fig.3 Dependence of fracture strength upon misorientation of blocks for: 1. Al 2. Zn 3. Cu 4. Ag 5. Ni 6. NaCl. The value of σ* was taken at lgτ=1 and 18°C (for NaCl at 400°C)