

Effect of magnetic field on the plastic deformation on aluminum at 4.2 K

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The velocity of fast dislocations in aluminum during the plastic deformation process is estimated. The method is based on the dependence of the electron deceleration on the magnetic field intensity predicted by V. Ya. Kravchenko. The linear dependence of the velocity on σ for small deformations becomes quadratic at the moment of fracture.

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The character of the plastic deformation in metals at liquid helium temperatures is subject to considerable influence by the conduction electrons. For fast dislocations, moving over the barrier with the application of a load $\sigma > \sigma_0$ (σ_0 is the yield limit), this influence is evident in terms of the electron deceleration force $F = B_0 V$ (V is the dislocation velocity, the electron deceleration coefficient B_0 has been calculated in Ref. 1). In a strong magnetic field ($\omega_H \tau \gg 1$, where ω_H is the cyclotron frequency, τ is the mean transit time of charge carriers), as shown by Kravchenko,^[2] an increase should occur in the electron deceleration: $B_H = B_0 \omega_H \tau$ for low dislocation velocities ($V \ll b/\tau$) and $B_H = B_0 \omega_H \tau (b/V\tau) \ln(V\tau/b)$ for high velocities ($V \gg b/\tau$), where b is the Burgers vector.

If the testing machine is stopped at some moment of active deformation and the deformed crystal is placed in a strong magnetic field H , assuming that no dislocation multiplication occurred during the time from the moment the test is stopped until the application of H , then a stress discontinuity $\Delta\sigma_H = \sigma_H - \sigma$ should appear, caused by a change in the deceleration force:

$$b\Delta\sigma_H = V(B_H - B_0). \quad (1)$$

The stopping of the testing machine must be brief in order that no appreciable stress relaxation $\Delta\sigma_r$ would occur. The quantity $\Delta\sigma_r$ must also be taken into consideration in determining the magnitude of the discontinuity $\Delta\sigma_H$.

The experiment was conducted at liquid helium temperature in a longitudinal magnetic field having an intensity of up to 50 kOe. Aluminum sample with a purity of at least 99.999% Al was chosen as the subject for the test. With this choice it was ensured that $\omega_H \tau \gg 1$ before the onset of the deformation. The samples were prepared by cold drawing with a reduction $\ln(L/L_{\text{init}}) = 2$ (L_{init} is the length of the blank, L is

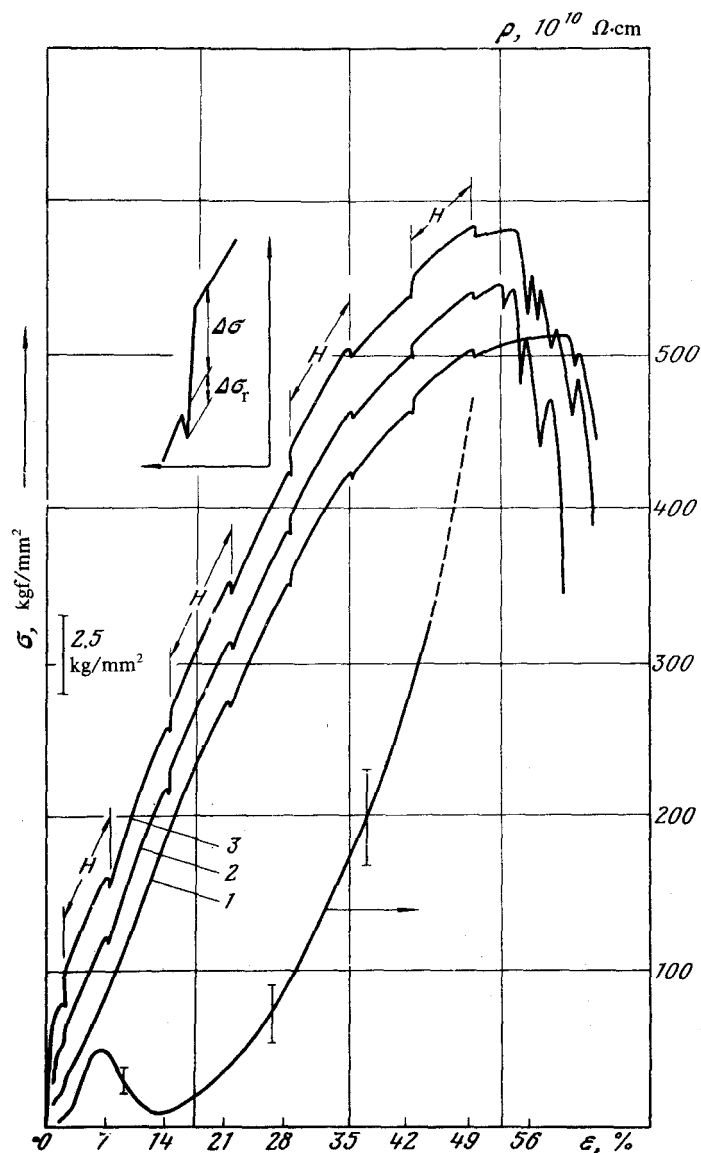


FIG. 1. Aluminum deformation curves with repeated application and removal of magnetic field H . 1—for $H = 0$ and $H = 20$ kOe, 2—0 and 40 kOe, 3—0 and 51 kOe. The deformation interval in the magnetic field is denoted by symbol H . Inset shows shape of hardening jump $\Delta\sigma_{0H} = \Delta\sigma + \Delta\sigma_r$. Curves 1 and 2 have been dropped along the ordinate σ . The dependence of the electrical resistance on the degree of deformation is shown at right.

the length after drawing), the clamped ends were pressed in a die. The working portion of the samples was a cylinder, 15 mm long and 3 mm in diameter; the deformed layer was removed from its surface by etching, after which it was electropolished. The samples were annealed at $T = 400^\circ\text{C}$ for 6 h. The high-temperature annealing of the severely deformed aluminum reduced the grain size to 0.5–1.0 mm.

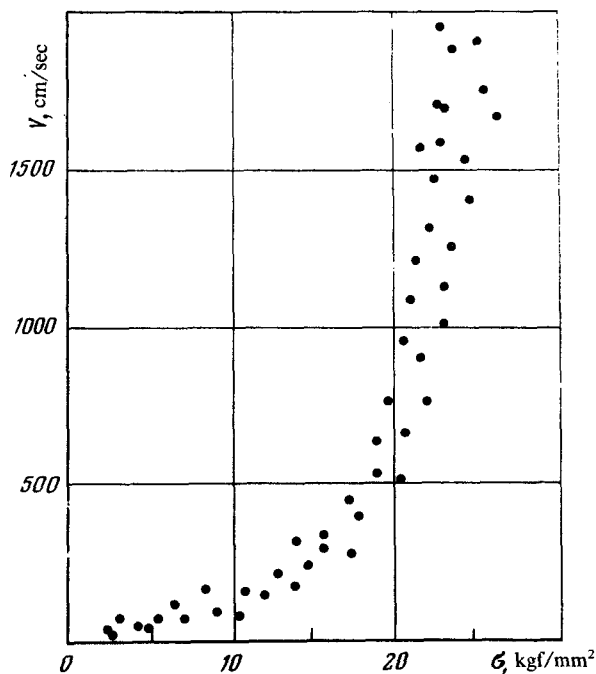


FIG. 2. Dependence of velocity of fast dislocations in aluminum on the applied stress at $T = 4.2$ K.

The samples were subjected to a tension at a constant rate of $\dot{\epsilon} = 10^{-5} \text{ sec}^{-1}$, provided by a deformation machine similar to that described in Ref. 3. The pull rods and clamps of the machine were made from a nonmagnetic and stiff material. The recorder sensitivity was no worse than 0.05 kgf/mm^2 . The curves of the deformation and electrical resistance during tension were traced on an x-y recorder.

The test was performed in the plastic deformation region up to the moment when the sample broke. In each test H was varied from zero to a fixed value only after the testing machine was stopped, Fig. 1. For $H = 0$ an appreciable stress relaxation was observed in some cases during the moments the machine was stopped. After the field was applied, the machine was turned on again; the sudden jump $\Delta\sigma$ in stress occurred at the very outset of the continuation of the stretching. The increase of $\Delta\sigma_{0H} = \Delta\sigma + \Delta\sigma_r$. For $H = \text{const}$ the machine was stopped only during the time when the field was removed, after which it was again turned on, and the jump in the stress $\Delta\sigma_{H_0}$, like in $\Delta\sigma_{0H}$, occurred at the very outset of the continuation of the stretching. With the machine stopped no $\Delta\sigma_r$ was observed in the magnetic field. In this situation all the jumps $\Delta\sigma_{0H}$, recorded at different instants of the deformation, were different, the $\Delta\sigma_{H_0}$ were also not the same and, in turn, $\Delta\sigma_{H_0}$. The fact that the jumps $\Delta\sigma_{0H}$ and $\Delta\sigma_{H_0}$ occurred not at the moments of application and removal of , but during the stretching under the influence of different external parameters, i.e., for $H = 0$ or $H = \text{const}$, favors the conclusion that the observed effect is related to changes in the aluminum strength. In addition, a calibration test was made: under the same conditions, i.e., at $T = 4.2 \text{ K}$ and $H = 0$ and 51 kOe , the stress-strain curve of commercial pure aluminum ($\omega_H \tau \ll 1$) was traced. No changes were observed in the

deformation curve. Turning on the field H without stopping the testing machine also leads to hardening, but the $\Delta\sigma_H$ is not so well pronounced since it is stretched out along the abscissa axis relative to the time when the field is introduced.

The free transit time of the current carriers in the original aluminum was estimated by the dimensional effect method^[4]; it was found to be equal to $\tau = 6 \times 10^{-10}$ sec. During the deformation the change in τ was estimated from the electrical conductivity value, Fig. 1. As is seen, for a relative deformation of the order of $\epsilon = 10\text{--}14\%$ a decrease is observed in the electrical resistance ρ ; in some cases it fell to the residual value. This decrease in ρ during the stretching process deserves attention. It is known that polycrystals with small grain size are quasi-isotropic. During deformation the quasi-isotropy can disappear; the change in the shape of the sample itself leads to a change in the mutual orientations of the crystallites. The fact that the diameter in certain portions of the deformation sample became greater than before elongation is a direct indication of rotation of crystallites in our experiment. In aluminum the direction of preferred orientation is $[111]$. The degree of preferred orientation is determined by the amount of deformation. In addition to the development of texture, leading to an increase in the the conductivity along the fibers,^[5] lateral slipping processes develop, accompanied by an increase in the electrical resistance. The development of these countering processes occurs at different ϵ values; this explains the shape of the curve.

The strong-field condition at $H = 50$ kOe and $T = 4.2$ K weakens at $\epsilon = 35\text{--}40\%$ and ceases to exist only the third stage of deformation. The mean velocity of the dislocations can be calculated in accordance with (1) from the magnitude of the stress jump $\Delta\sigma_H$ and the current carrier transit time τ , determined experimentally at some moment of deformation. The dislocation velocity values, determined from the value of the jumps $\Delta\sigma_{OH}$, are shown in Fig. 2. One possible reason for the fact that $\Delta\sigma_{OH} \neq \Delta\sigma_{H_0}$ may be the difference in the dislocation velocities in real crystals at different moments of plastic deformation. This is apparently due to the presence in the aluminum of a multitude of slip systems and the nonsimultaneity of their action; each of the systems has its own dislocation density and velocity, different from the others. The order of magnitude of the velocity and the linearity of its dependence on the applied stress at not too large deformations agree well with the results obtained by other methods, such as in Ref. 6. This gives a basis for assuming that the interpretation of the effect used here is valid. The error in the determination of the mobility from our estimates does not exceed $\pm 15\%$. As seen from Fig. 2, with an increase in σ the dependence of the velocity on the applied stress rises considerably and from linear turns into a quadratic.

In our experiments the dislocation flow is $NV = \dot{\epsilon}/b \sim 10^2\text{--}10^3$ (cm·sec)⁻¹. Therefore only the isolated fast dislocations ($N \sim 1\text{--}10$ cm²) move with the higher velocities indicated in Fig. 2. As shown in Ref. 7, only the dislocations parallel to H experience the influence of the magnetic field. In our geometry these are apparently portions of dislocation loops; their average density can correspond to that quoted above.

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