# Influence of dynamic intermediate state on the softening of a type I superconductor

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It is shown that the electric current softens a type I superconductor in the intermediate state during a plastic deformation.

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In studying the plastic flow of type I and II semiconductors at temperatures below the superconducting transition temperature, the dislocation retardation by the conduction electrons and by the magnetic structure of the intermediate and mixed state must be taken into account.[1–3] Thus, a hardening caused by the trapping of defects at the interface of the normal and superconducting phases or in the magnetic vortex structure can be observed as a result of deformation of lead in the intermediate state[2] and of alloys of the lead-indium system in the mixed state.[3]

In contrast to the static magnetic structure, the passage of an electric current through a type I superconductor in the intermediate state results in the appearance of a drift of the phase boundary.[4] This makes it possible to examine the influence of the dynamic state on the motion of crystal lattice defeats.

This paper describes the observed decrease of the deforming stress due to the flow of an electric current through a type I superconductor in the intermediate state and its dependence on certain experimental parameters.

Figure 1a illustrates the variation of the strain-hardening curve as a result of simultaneous influence of the magnetic field $H$ and electric current with a density $j$ ($H$ and $j$ are mutually perpendicular and $j$ is parallel to the strain axis of the sample): the deforming stress increases by the amount $\delta\sigma_{\rm int}$ and the electric current softens the metal by $\delta\sigma_{\rm cur}$ in the region where the intermediate state exists.

Figure 1b shows the variation $\delta\sigma_{\rm int}/\delta\sigma_{\rm ns}$ of the relative deforming stress of

  

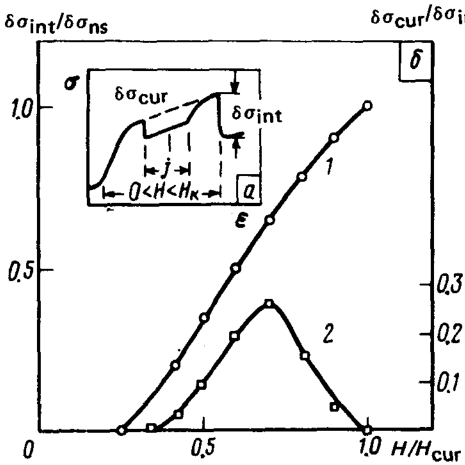


FIG. 1. (a) Variation of deforming stress of type I superconductor as a result of application of the magnetic field and the flow of electric current; (b) dependence of the relative hardening of lead in the intermediate state $\delta\sigma_{int}/\delta\sigma_{ns}$ (1) and of the softening due to action of current $\delta\sigma_{cur}/\delta\sigma_{int}$ (2) on the reduced magnetic field $H/H_c$.

99.9996% pure polycrystalline lead in the intermediate state at 4.2 K (curve 1) ($\delta\sigma_{ns}$ is the sudden stress change due to transition from the superconducting state to the normal state) and the variation of the relative hardening $\delta\sigma_{cur}/\delta\sigma_{int}$ ($j = 3.5$ A/mm$^2$) (curve 2) as a function of $H/H_c$($H_c$ is the critical magnetic field). It follows from Fig. 1b that $\delta\sigma_{int}/\delta\sigma_{ns}$ increases monotonically with increasing concentration of the normal phase in the sample and the $\delta\sigma_{cur}/\delta\sigma_{int}$ curve has a maximum at $H/H_c = 0.7$. It must be noted that, according to Ref. 2, this magnetic field intensity corresponds to an intermediate-state structure with the largest number of boundaries between the normal

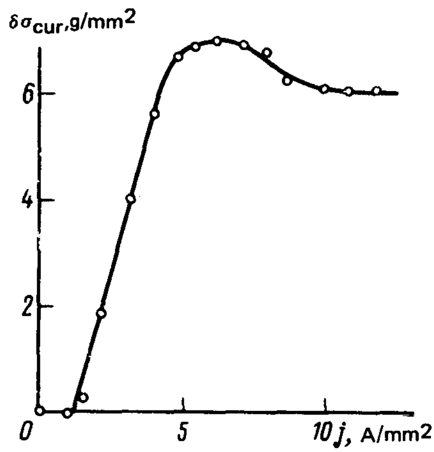


FIG. 2. Influence of current density on the softening of lead at $H/H_C = 0.7$.

and the superconducting phases.

The $\delta\sigma_{int}$ increase is the deforming stress is determined by the retardation of the dislocation by the conduction electrons and static phase boundaries,[2] and the $\delta\sigma_{cur}$ softening may be caused by: 1) the ponderomotive force acting on the sample, 2) thermal excitation of a dislocation, and 3) interaction between the dislocation and magnetic fluxes.

An estimate of the ponderomotive force ($\sim 1$ g/mm$^2$) and of the heat release ($\sim 10^{-4}$ W), and the equality $\delta\sigma_{cur} = 0$ for the strain in the superconducting and normal states make it possible to eliminate these effects and to assume that the observed softening of type I superconductor with current in the intermediate state is caused by the change in the dislocation mobility resulting from the interaction of the moving domains with the flow (the force of such interaction per unit length of a dislocation with Burgers vector $b$ is $F_{in} = \delta\sigma_{cur} b \sim 10^{-2}$ dyne/cm).

If we regard the system of boundaries between the normal and the superconducting phases as a medium that possesses a viscosity coefficient $B_n$ and drifts with a velocity $v_h$ in the presence of electric current, then we can write

$$\delta\sigma_{cur} = \frac{B_h}{b}(v_d - v_h) \qquad (1)$$

for the dislocation velocity $v_d$.

The amount of softening due to the dynamic intermediate state is shown in Fig. 2, as a function of the electric current density for $H/H_c = 0.7$. The $\delta\sigma_{cur}(j)$ dependence has a threshold nature; the proportionality between $\delta\sigma_{cur}$ and $j$ may indicate that the domain velocity increases linearly ($j \sim v_h$); the subsequent saturation and even some decrease in $\delta\sigma_{cur}(j)$ are probably determined by the increase in concentration of the normal phase due to the intrinsic magnetic field of the current or the evolution of Joule heat, which destroys the structure of the intermediate state.

Using Eq. (1) and the data of Fig. 2, we estimate the viscous retardation coefficient to be equal to $B_h \sim 10^{-5}$ dyne·sec·cm$^{-2}$.

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