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Pressure and Strain Rate Dependence of Dynamic Recovery in NaCl

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Abstract

Crystals of NaCl have been deformed at room temperature in compression at pressures up to 10 kb at two different strain rates having a ratio of 24. At both strain rates, τ_{III} (the stress for the onset of stage III work hardening) decreases with pressure up to a pressure of about 5 kb, whereupon, within experimental error, no further change is observed. The decrease in τ_{III} (up to 5 kb) is more rapid at high strain rate ($d \ln \tau_{\mathrm{III}}/dP \simeq -0{\cdot}34$/kb) than at low strain rate ($d \ln \tau_{\mathrm{III}}/dP \simeq -0{\cdot}25$/kb) so the strain-rate sensitivity of τ_{III}, $(\partial \ln \tau_{\mathrm{III}}/\partial \ln \dot{\epsilon})_{T,P}$, is decreased by about an order of magnitude between 1 atm and 5 kb.

Stage III work hardening in NaCl is believed to be controlled by the thermally activated, stress-assisted, cross-slipping of screw dislocations. The decrease of τ_{III} with pressure may be qualitatively associated with an increase in the stacking-fault energy γ, which is dependent on pressure through a strong dilatation of the lattice in the vicinity of the fault. From cross-slipping theory the dependence of the strain-rate sensitivity of τ_{III} on pressure may be calculated. The small increase predicted is, however, in clear disagreement with the present results.

§ 1. Introduction

The work hardening behaviour of NaCl has been examined in considerable detail by Hesse (1965) and Davidge and Pratt (1964). In particular, Hesse, has examined the dependence of the stress for stage III work hardening, τ_{III}, on strain rate and temperature and established a relation of the form

$$\ln(\tau_{\mathrm{III}}/\tau_0) = (kT/A)\ln(\dot{\epsilon}/\dot{\epsilon}_0), \quad (1)$$

where $\dot{\epsilon}$ is the strain rate, T the absolute temperature, k Boltzmann's constant, τ_0 and $\dot{\epsilon}_0$ are constants independent of T and $\dot{\epsilon}$ and A is a function of the stacking-fault energy, γ. Equation(1) derives from the cross-slip theory of Seeger, Berner and Wolf (1959) (SBW) and of Haasen (1958), leading Hesse to suggest that one may associate dynamic recovery in NaCl with the onset of thermally activated, stress-assisted cross slip of screw dislocations. Experimental support of the cross slip mechanism for stage III followed when the appearance of cross slip traces at the onset of stage III was observed in the electron microscope (by replication) by Matucha and Haasen (1967) and Matucha (1968). More recently Davis and Gordon (1969 a) and Aladag, Davis and Gordon (1970) have found that τ_{III} in NaCl is strongly dependent on pressure. According to a qualitative application of the SBW cross slip theory, this is associated with an enhancement of the cross slip process at high pressure (Davis and Gordon 1969 a, b) through an increase of the stacking-fault energy, γ, with pressure. This latter proposal follows from the work of Fontaine (1968) who predicted that stacking faults in the alkali halides should cause a strong local dilatation of the lattice ($\epsilon_0 = \delta d_{110}/d_{110} \simeq 0{\cdot}3$) and thus γ should be sensitive to pressure. Subsequently Haasen, Davis, Aladag and Gordon (1970) found that using the SBW theory, and incorporating the pressure dependence of γ according to Fontaine and Haasen (1969), one can predict a value of $(d \ln \tau_{\mathrm{III}}/dP)_{1\,\mathrm{atm}}$ which is in fair agreement with previous experimental data. This suggests that the influence of pressure on stage III in NaCl may be described in some detail by the SBW theory. It is of interest, therefore, to pursue this subject further by examining the decrease of τ_{III} with pressure as a function of strain rate so that comparison may be made with predictions of the theory. This may be done conveniently by comparing τ–ϵ curves for two significantly different strain rates.

§ 2. EXPERIMENTAL

The mechanical testing device (minitester) employed has been described in detail by Gordon and Mike (1967) and Davis and Gordon (1968). The drive components of the system consist of an 1800 r.p.m. syncronous motor, a planetary gear system, and 0·3175 cm pitch drive screw. By adjusting the gear ratio one can achieve different compression rates. Here we have employed gear trains of 60 000 : 1 and 2500 : 1 reduction for compression rates of 0·00952 cm/min and 0·229 cm/min respectively, i.e. a strain-rate ratio of 24. The minitester is placed inside a pressure vessel and pressure generated by a 200 000 p.s.i. capacity Harwood system; pressure is monitored by a manganin cell. Samples are tested in pentane, with a trace of oil for lubrication of moving parts. The use of a low viscosity fluid such as pentane is essential to minimize the viscous drag on the motor at high pressure. It is found that no decrease in motor speed obtains to pressures of about 8·5 kb; at 10 kb a decrease of up to 20% is possible. For the strain-rate ratio employed here a 20% change from nominal speed is negligible.

A large batch of annealed and cleaved samples was obtained from the Harshaw Chemical Co., with nominal dimensions of $1{\cdot}27 \times 0{\cdot}635 \times 0{\cdot}635$ cm. The sample ends are lapped flat and parallel in a vee-block and the sample is tested in compression at room temperature. The compression platens are lubricated with oil or a PTFE sheet. The top platen has a hemispherical head which bears on the load cell and is free to rotate about the bearing point. This facilitates alignment of the system and approximates the condition of laterally free platens. Specimens deform primarily on one family of parallel $\{110\}$ $\langle\bar{1}10\rangle$ slip systems. For the specimen shape employed here one finds the nominal shear strain is approximately four times the compressive strain. Thus, for the compression rates noted above the shear strain rates are $\dot{\epsilon} = 5 \times 10^{-4}$/sec and $\dot{\epsilon} = 1{\cdot}2 \times 10^{-2}$/sec. At a compression of about 20% (0·254 cm) the sample ends remain parallel to