THE EFFECT OF THE STRAIN AMPLITUDE CHANGES ON THE STRESS AMPLITUDE AND RESISTIVITY OF TORSIONALLY FATIGUED COPPER

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Polycrystalline copper wires were cyclically strained in torsion in liquid nitrogen and the effect of the strain amplitude changes on the stress amplitude and resistivity was followed. It was found that both stress amplitude and resistivity are able to increase or decrease in dependence on the applied plastic strain amplitude. When the strain amplitude was decreased, the reversibility was not complete. By means of intermediate annealing it was found that both the dislocation density and the point-defect concentration follow the changes of the plastic strain amplitude.

1. INTRODUCTION

The response of f.c.c. metals to cyclic straining was mostly investigated using the measurement of mechanical properties and electron-microscopic observations (for review see [1]). In polycrystalline copper the independence of the final saturated stress amplitude on the previous cyclic history was shown both for low-cycle [2] and high-cycle [3] fatigue. The dislocation structure corresponding to the applied plastic strain amplitude and temperature of the test was found as a cell structure in the high amplitude region and band structure in the low amplitude region. However, once a dislocation cell structure was formed, even the prolonged cycling with low amplitude did not change this structure back to the band structure [3]. Therefore the dislocation structure depends to a certain extent on the strain history and is not always a determining factor of the stress amplitude.

The changes of the dislocation density were measured by transmission electron microscopy during fatigue hardening [4]. In saturation, however, this method is difficult to apply due to strongly inhomogeneous distribution and high local dislocation density. In particular, it would be difficult to measure precisely the small dislocation density changes following the strain amplitude changes.

Indirect experimental techniques as the resistivity, internal friction or stored energy measurements often used for the investigation of the plastic deformation of metals [5, 6] were applied to fatigue only incidentally [1, 7]. Resistivity measurements on wires fatigued in torsion [8, 9, 10] can be made fairly precisely, and therefore they are well suited for tracing the slight changes of the defect density during strain amplitude changes. Previous measurements [8, 11] have shown that the resistivity saturates during cycling and increases again after the drop due to intermediate annealing. In this work the changes in the stress amplitude and resistivity due to the strain amplitude changes are investigated.

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2. EXPERIMENTAL PROCEDURE

Specimens 10 cm in length were cut from the 99.999% pure copper wire of 1 mm in diameter supplied by Johnson & Matthey. They were annealed for one hour at a temperature of 400 °C in purified argon. The final grain size was about 35 µ.

The specimens immersed in liquid nitrogen were cycled under constant total strain amplitude in torsion in an apparatus mentioned earlier [8]. The torsion angle \( \omega \) giving the total strain amplitude could be varied continuously from 0 to 2\( \pi \). The small axial extension was measured with the dial gauge. It was appreciable only during the hardening stage at higher amplitudes of the deformation.

Electrical resistance was measured in liquid nitrogen by the conventional potentiometric method with the use of the dummy specimen [12]. The increment of the electrical resistivity was calculated from the specimen resistance \( R' \) and axial engineering strain \( \varepsilon \) using the relation

\[
Aq = \frac{\rho_{20}}{R_{20}} \left( \frac{R'}{(1 + \varepsilon)^2} - R \right);
\]

\( \rho_{20} \) is the resistivity of our copper at 20 °C, \( R_{20} \) the resistance of the specimen at the same temperature and \( R \) the original value of the resistance of the specimen. The uncertainty in the electrical resistivity determination was \( 3 \times 10^{-11} \Omega \, \text{cm} \).

In order to determine the amplitude of the plastic deformation and to follow at least approximately, the stress amplitude we have measured the angle of backlash \( \alpha \) and calculated the plastic strain amplitude and the amplitude of the mean shear stress. As torsion is an inhomogeneous deformation we have used the average values over the cross-section of the specimen. Moreover, in order to make possible the comparison with other modes of deformation, we have transformed the macroscopic shear stress and strain into the mean shear stress and strain using the factor 1.65 derived by BISHOP and HILL [13] (see also [14]). The mean shear stress amplitude was calculated according to the relation

\[
\tau = \frac{1}{1.65} \frac{2}{3} \frac{r_0}{l_0} G (1 + \varepsilon)^{-3/2} \alpha,
\]

\( r_0 \) and \( l_0 \) is the initial radius and length of the specimen, \( G \) the shear modulus, \( \varepsilon \) the axial engineering strain and \( \alpha \) the angle of backlash. This method did not allow to determine the mean shear stress amplitude very precisely. The typical error was 0.2 kg/mm². The amplitude of the mean shear strain is

\[
\tilde{\gamma}_a = 1.65 \frac{2}{3} \frac{r_0}{l_0} (1 + \varepsilon)^{-3/2} (\omega - \alpha).
\]

Cumulative mean shear strain \( \gamma_c \) is obtained summing up the absolute values of the plastic strain

\[
\gamma_c = 4 \sum \tilde{\gamma}_a.
\]