THE AVERAGE REST TIME, τ, OF IMMOBILE DISLOCATIONS

Introduction

It is quite reasonable to assume that there is a probability for immobilised dislocations to remobilise during plastic deformation. One important factor supporting such an assumption is that the system gains energy by reusing already existing dislocations instead of creating new ones. The phenomenon of re-mobilisation of dislocations has also been frequently observed in in-situ transmission electron microscopy studies of the plastic deformation process in metals, see for instance PAPER 1 in this set of presentations.

In the Bergström theory, see PAPER 1 *"A dislocation model for the plastic deformation of single-phase alpha-iron - a résumé"* , it is assumed that the plastic deformation process in metals and alloys is controlled by the creation, the immobilisation and the remobilisation of dislocations according to the following expression

$$\frac{d\rho}{d\varepsilon} = \frac{m}{b \cdot s} - \Omega \cdot \rho \qquad (1)$$

where ρ is the total dislocation density at true strain ε, m is the Taylor constant, b the nominal value of the Burgers vector, s is the mean free path of dislocation motion and Ω is the dislocation re-mobilisation parameter.

Derivation of an expression for the mean rest-time τ of immobilised dislocations

According to the definition of the parameter Ω it is a measure of the probability by which immobilised dislocations re-mobilise. Hence, Ω is also a measure of the average time, τ, the immobile dislocations remain in rest before they re-mobilise (1). This measure is important in analysing for instance static and dynamic strain ageing and also in deriving a theory for Ω as a function of temperature and strain rate.

Now in order to re-place ε by time t as a variable in eqn(1) we may re-write this equation as

$$\frac{d\rho}{dt} \cdot \frac{dt}{d\varepsilon} = \frac{m}{b \cdot s} - \Omega \cdot \rho \qquad (2)$$

Since

$$\frac{dt}{d\varepsilon} = \frac{1}{\dot{\varepsilon}} \qquad (3)$$

where $\dot{\varepsilon}$ is the strain rate eqn(2) may be written

$$\frac{d\rho(t)}{dt} = \frac{m \cdot \dot{\varepsilon}}{b \cdot s} - \Omega \cdot \dot{\varepsilon} \cdot \rho(t) \qquad (4)$$

In order to derive an expression for τ in terms of the present dislocation model we will proceed as follows.

Let us assume that the material has been pre-strained and contains a dislocation density $\rho(\varepsilon_p)$. On continued straining these dislocations re-mobilise at the following rate

$$\frac{d\rho(t)}{dt} = -\Omega \cdot \dot{\varepsilon} \cdot \rho(t) \qquad (5)$$

Now, with the boundary condition $\rho=\rho(\varepsilon_p)$ at t=0 we obtain after integration

$$\rho(t) = \rho(\varepsilon_p) \cdot e^{-\Omega \cdot \dot{\varepsilon} \cdot t} \qquad (6)$$

The average rest time τ can now be calculated from the expression

$$\tau = \frac{\int_0^\infty t \cdot \rho(t) \cdot dt}{\int_0^\infty \rho(t) \cdot dt} \qquad (7)$$

and after integration we have

$$\tau = \frac{1}{\Omega \cdot \dot{\varepsilon}} \qquad (8)$$

Hence, τ is completely determined by the experimental value of strain rate and the re-mobilisation constant Ω.

For an ordinary ferritic steel strained at room temperature the re-mobilisation constant is approximately equal to 5, see PAPER 1, and for a strain rate of 10^{-3} s^{-1} we have according to eqn(8) that $\tau \approx 3$ minutes. Thus, it is possible from this simple form of calculation to estimate the risks for effects of Cottrell-locking of the immobile dislocations during deformation as well as dynamic strain ageing effects.

It is also possible, by proceeding from eqn(8), to derive a simple expression for the temperature and strain – rate dependences of the dislocation re-mobilisation factor Ω. Such a derivation is presented in PAPER 1 (2)

References

1. Y.Bergström, Reviews on powder metallurgy and physical ceramics 2(1983)79-265
2. See Paper 1 – A dislocation model for the plastic deformation of single-phase alpha iron – a résumé.