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DEPENDENCE OF RELAXATION TIMES ON THE MATERIAL MICROSTRUCTURE FOR DIFFERENT MECHANISMS OF PLASTICITY

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Abstract. On the basis of the Maxwell model for very viscous liquid we derive equations for definition of characteristic relaxation times that are used in the integral criterion of plasticity. Relaxation times are constants for the material with current microstructure and do not depend on the features of the deformation process, but they change at the change of the main deformation mechanism of plasticity. We proposed the equations that connect the characteristic time of plastic relaxation with the scalar dislocation density and grain size of the material for dislocation plasticity and creep consequently.

1. Introduction

There are a number of models of plastic deformation, which takes into account not only the yield strength as a barrier stress for incipience of the plastic deformation, but the dynamic properties including the finite rate of plastic relaxation as well. Some of these models explicitly use the parameter of characteristic time of plastic relaxation, which is supposed to be a material constant unchangeable during the deformation. On the other hand, the characteristic time changes at variation of the material microstructure or at the change of the dominant mechanism of plastic deformation [1]. Comparison of the expressions [1] followed from Maxwell model of highly viscous fluid with the constitutive equations of dislocation plasticity or creep allows one to obtain the expressions for corresponding characteristic times of relaxation [1, 2]. The Maxwell approach can be generalized by means of the integral criterion of plasticity [2, 3], which is reduced to Maxwell model at low strain rates.

2. Expressions of characteristic times of plastic relaxation

Neglecting the static yield strength in comparison with the dynamic one and using Orowan equation [1] one can obtain the following expression for the characteristic time of relaxation at the dislocation slip [1, 2]

$$\tau_D = \frac{\chi B_D}{\rho_D G b^2}, \tag{1}$$

where ρ_D is the scalar density of dislocations; $Gb^2\rho_D$ is the total elastic energy of dislocation lines in unit volume; B_D is the phonon drag coefficient [4] that characterizes the dissipation rate of the kinetic energy of dislocations; $\chi = (1 - V_D^2 / c_t^2)^{-3/2}$ is the dynamic factor that takes into account the increase of the phonon drag at the increase of dislocation velocity V_D to values comparable with the transverse sound velocity $c_t = \sqrt{G/\rho}$.

In the cases of creep mechanisms proposed by Coble, Nabarro and Herring, and Harper and Dorn [5], the characteristic times are defined by Eqs. (2), (3) and (4), respectively

$$\tau_{gb} = \frac{k_b T d^3}{A_C D_{gb} G b^3 \delta}, \tag{2}$$

$$\tau_{NH} = \frac{k_b T d^2}{A_{NH} D_l G b^3}, \tag{3}$$

$$\tau_{HD} = \frac{k_b T}{A_{HD} D_l G b}, \tag{4}$$

where A_C ~ 30-50, A_{NH} ~10-15, A_{HD} ~10^{-11} are the constants of corresponding models [5], T is the temperature, d is the grain diameter, δ is the grain boundary thickness, k_b is Boltzmann constant. Value of the characteristic time of relaxation considerably depends on the coefficients of self-diffusion of atoms in bulk D_l and along the grain boundaries D_{gb} .

The obtained expressions can be used for evaluation of the strain rate influence on the dynamic yield strength of materials. Fig. 1 shows the calculation results for direct and inverse Hall-Petch effect [5] in conditions of dynamic deformations in a wide range of strain rates. Quasistatic part is calculated using the models for barrier stresses for the dislocation slip [4] and the grain boundary sliding [6]. Dynamic part is calculated using the characteristic time of relaxation for dislocation slip, Eq. (1), that was preliminary fitted in comparison with the experimental data [7], as well as the characteristic time of creep according to Coble mechanism, Eq. (2).

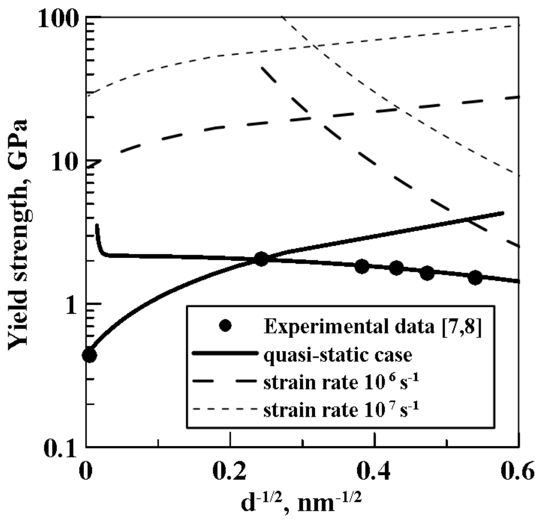

Fig. 1. Yield strength versus grain size in Hall-Petch coordinates at three various strain rates 10^3-$10^7 s^{-1}$. Lines show calculation results, dots show experimental data [7, 8].

3. Conclusions

Similar to Taylor and Hall-Petch relations for static yield strength, it is possible to reveal the structural dependences for the dynamic parameters, namely, for the characteristic times of plastic relaxation. The obtained relations allow one to predict the dynamic yield strength in wide ranges of material parameters, such as the grain size, the concentration of defects and the temperature. It is also possible to determine the transition point between different plasticity mechanisms and to follow its variation at the strain rate increase.

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