Dislocation structure and kinetics in slip-twin model

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MSU Twin Meeting, Düsseldorf – October 6th, 2009

Dislocation structure parametrization

Internal variables:

- N^α edge dislocation densities $\varrho^\alpha_{\text{edge}}$
- N^α dipole densities $\varrho^\alpha_{\text{dipole}}$

Derived measures:

- τ^α_c threshold shear stress
- λ^α mean distance between 2 obstacles seen by a dislocation

Dislocation structure parametrization

Threshold stress τ^α:

$$\tau_{\mathrm{c}}^{\alpha} = G_{\mathrm{iso}}\, b^{\alpha} \sqrt{\sum_{\tilde{\alpha}=1}^{N^{\alpha}} \xi^{\alpha\tilde{\alpha}} \left(\varrho_{\mathrm{edge}}^{\tilde{\alpha}} + \varrho_{\mathrm{dipole}}^{\tilde{\alpha}}\right)}$$

with:

- G_{iso} Isotropic shear modulus
- b^{α} Burgers vector of slip system α
- $\xi^{\alpha\tilde{\alpha}}$ interaction strength (Kubin et al. 2008)

Orowan's kinetics

Shear rate $\dot{\gamma}^\alpha$:

$$\dot{\gamma}^\alpha = \varrho^\alpha_{\text{edge}}\, b^\alpha\, v^\alpha_{\text{glide}}$$

Velocity v^α_{glide}:

$$v^\alpha_{\text{glide}} = v_0 \exp\left[-\frac{Q}{k_{\text{B}}\, T}\left(1 - \left(\frac{|\tau^\alpha|}{\tau^\alpha_{\text{c}}}\right)^p\right)^q\right] \text{sign}(\tau^\alpha)$$

with:

- v_0 Velocity pre-factor
- Q Activation energy for dislocation glide
- $k_{\text{B}}\, T$ Boltzmann energy

Dislocation multiplication

Multiplication:

$$\dot{\varrho}^{\alpha}_{\text{multiplication}} = \frac{|\dot{\gamma}^{\alpha}|}{b^{\alpha}\,\lambda^{\alpha}}$$

Multiplication constant:

$$\lambda^{\alpha} = k_{\lambda}\left(\varrho^{\alpha}\right)^{-1/2}$$

Dislocation dipole formation

Dipole formation:

$$\dot{\varrho}^{\alpha}_{\text{formation}} = 2\,\frac{2\,\max(\hat{d}^{\alpha}, \check{d}^{\alpha})}{b^{\alpha}}\,\frac{\varrho^{\alpha}_{\text{edge}}}{2}\,|\dot{\gamma}^{\alpha}|$$

Upper stability limit for dipoles $\hat{d}^{\alpha}$:

$$\hat{d}^{\alpha} = \frac{1}{8\,\pi}\,\frac{G_{\text{iso}}\,b^{\alpha}}{1-\nu}\,\frac{1}{|\tau^{\alpha}|}$$

Spontaneous annihilation of 2 single dislocations

Single–single annihilation:

$$\dot{\varrho}^{\alpha}_{\text{single–single}} = 2\,\frac{2\,\check{d}^{\alpha}}{b^{\alpha}}\,\frac{\varrho^{\alpha}_{\text{edge}}}{2}\,|\dot{\gamma}^{\alpha}|$$

Lower stability limit of dipoles $\check{d}^{\alpha}$:

$$\check{d}^{\alpha} \propto b^{\alpha}$$

Spontaneous annihilation of one single dislocation with a dipole constituent

Single–dipole constituent annihilation:

$$\dot{\varrho}^{\alpha}_{\text{single–dipole}} = 2\,\frac{2\,\check{d}^{\alpha}}{b^{\alpha}}\,\frac{\varrho^{\alpha}_{\text{dipole}}}{2}\,|\dot{\gamma}^{\alpha}|$$

Dislocation dipole climb

Dipole climb:

$$\dot{\varrho}^{\alpha}_{\text{climb}} = \varrho^{\alpha}_{\text{dipole}} \frac{2\, v_{\text{climb}}}{(\hat{d}^{\alpha} - \check{d}^{\alpha})/2}$$

Climb velocity $v^{\alpha}_{\text{climb}}$:

$$v^{\alpha}_{\text{climb}} = \frac{D\,\Omega^{\alpha}}{b^{\alpha}\, k_{\text{B}}\, T} \frac{G_{\text{iso}}\, b^{\alpha}}{2\,\pi\,(1-\nu)} \frac{1}{(\hat{d}^{\alpha} + \check{d}^{\alpha})/2}$$

Evolution of dislocation densities

Edge dislocation density rate:

$$\dot{\varrho}^{\alpha}_{\text{edge}} = \dot{\varrho}^{\alpha}_{\text{multiplication}} - \dot{\varrho}^{\alpha}_{\text{formation}} - \dot{\varrho}^{\alpha}_{\text{single–single}}$$

Dislocation dipole density rate:

$$\dot{\varrho}^{\alpha}_{\text{dipole}} = \dot{\varrho}^{\alpha}_{\text{formation}} - \dot{\varrho}^{\alpha}_{\text{single–dipole}} - \dot{\varrho}^{\alpha}_{\text{climb}}$$