Dislocation density based crystal plasticity model

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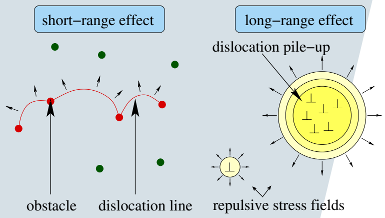
Introduction

During deformation of a polycrystal sample of FCC metal, the numerous interactions between its dislocations largely determine the constitutive behaviour. Here, two types of dislocations are distinguished, of which both the density evolution and their specific interactions are modelled:



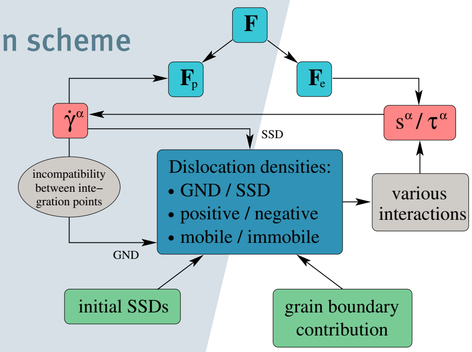
Interactions of statistically-stored and geometrically-necessary dislocation densities (SSD's and GND's).

Objective

To develop a model being capable of describing heterogeneous deformation inside grains, based on the microstructural physical dislocation processes, and hence reproduce the experimentally observed grain size dependent response.

Model

Solution scheme

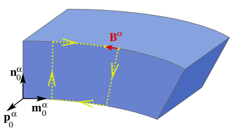


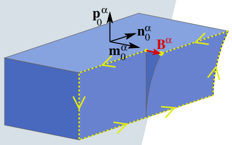
To implement this scheme into a FE environment, each grain is subdivided in finite elements, where up to 18 GND densities are considered as additional nodal variables.

Dislocation density evolution

The evolution of the 12 SSD densities follow from the slip rates through a traditional evolution equation. The GND densities are related to the gradients of crystallographic slip:

$$\rho^\alpha_{\text{GND, edge}} = \rho^\alpha_0 - \frac{1}{b}\left(\nabla_0 \gamma^\alpha \cdot \mathbf{m}^\alpha_0\right)$$

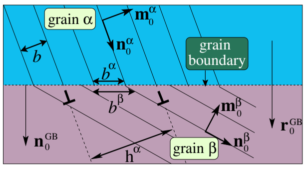




$$\rho^\alpha_{\text{GND, screw}} = \rho^\alpha_0 + \frac{1}{b}\left(\nabla_0 \gamma^\alpha \cdot \mathbf{p}^\alpha_0\right)$$

Furthermore, extra (initial) GND's (ρ_0^α) are assigned to integration points near grain boundaries, which are present to accomodate the crystallographic lattice misfit:

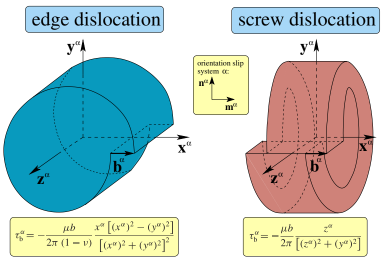
$$\rho^\alpha_0 \sim \text{sign}\left(\rho^\alpha_0\right)\frac{1}{h^{\alpha 2}} = \text{sign}\left(\mathbf{n}^\alpha_0 \cdot \mathbf{r}^{\text{GB}}_0\right)\frac{\left(\left|\mathbf{n}^\alpha_0\cdot\mathbf{n}^{\text{GB}}_0\right| - \left|\mathbf{n}^\beta_0\cdot\mathbf{n}^{\text{GB}}_0\right|\right)^2}{b^2}$$



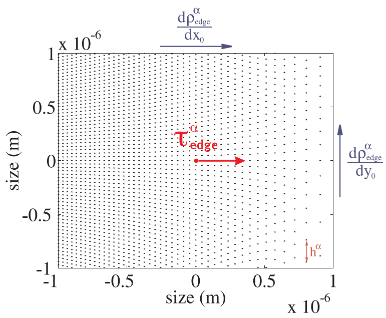
Dislocation interactions

In the constitutive model, the slip rate ($\dot{\gamma}^\alpha$) is determined by an extended flow rule as a function of:

- ☐ the slip resistance, which is coupled to the 12 SSD densities through short-range interaction coefficients.
- ☐ the back-stress, which is related to the (long-range) stress fields of single edge and screw dislocations:



After employing these back-stress relations to determine the resulting stress in the origin of a dislocation field (represented by the dots in the figure below), only GND density *gradients* appear to play a role:



$$\tau^\alpha_{\text{edge}} = \frac{\kappa_e \mu b A}{2\pi(1-\nu)}\left(\nabla_0 \rho^\alpha_{\text{edge}} \cdot \mathbf{m}^\alpha_0\right)$$

$$\tau^\alpha_{\text{screw}} = \frac{\kappa_s \mu b A}{2\pi}\left(\nabla_0 \rho^\alpha_{\text{screw}} \cdot \mathbf{p}^\alpha_0\right)$$

Discussion

The advantages of this model with respect to conventional crystal plasticity models are:

- ☐ distinction is made between the different *effects* of SSD's and GND's
- ☐ grain boundaries and their dislocations are included
- ☐ grain size dependency of FCC polycrystals is modelled

References:

[1] HARDER, J. A crystallographic model for the study of local deformation processes in polycrystals *International Journal of Plasticity* 15: 605–624 (1999).

[2] COTTRELL, A.H.: *Dislocations and Plastic Flow in Crystals* (Oxford University Press, 1961)

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