Mesoscopic modelling of plastic slip and internal stress

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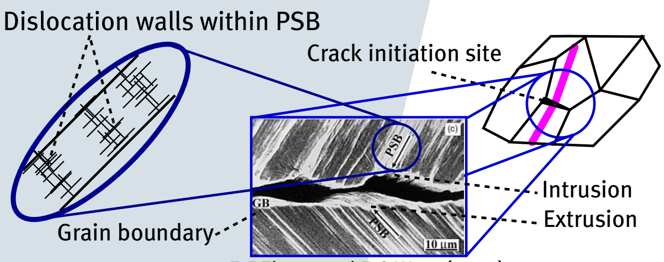
Objective

The aim of the project is to model high-cycle fatigue of structural elements by taking into account the underlying processes at the mesolevel.

Motivation

Experiments show that fatigue damage is initiated as intrusions and extrusions at the end of Persistent Slip Bands (PSBs). These intrusions and extrusions appear as a result of a different amount of net slip on glide planes within the band (Figure 1). It is crucial to model the development of PSBs and the dislocation structures associated to them in order to predict fatigue damage initiation.



Z.F.Zhang and Z.G.Wang(2003)

Figure 1 Mechanism of crack initiation

Continuum modelling

The deformation of a crystal lattice with respect to an imaginary perfect lattice can be expressed in terms of a displacement gradient $\vec{\nabla}\vec{u}$ (cf. [1, 2]). The total (compatible) deformation $\vec{\nabla}\vec{u}$ can be decomposed into a (possibly incompatible) plastic part $\boldsymbol{\beta}^p$ and a (also possibly incompatible) elastic part $\boldsymbol{\beta}^e$ (Figure 2):

$$\vec{\nabla}\vec{u} = \boldsymbol{\beta}^e + \boldsymbol{\beta}^p.$$

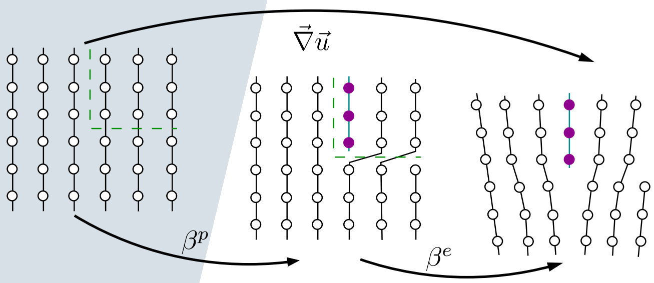


Figure 2 Decomposition of displacement gradient

A dislocation density tensor can be defined from the plastic distortion tensor as $\boldsymbol{\alpha} = -\vec{\nabla} \times \boldsymbol{\beta}^p$, where $\boldsymbol{\alpha}$ may be interpreted as a geometrically necessary dislocation (GND) density tensor.

The internal stress due to the presence of dislocations can be computed from the equilibrium equation by taking into account the plastic distortion tensor and proper kinematic and/or static boundary conditions.

Single slip case

Under the assumption of a plain strain state and single slip, the set of equations can be solved by the finite element method in order to derive the evolution of the GND density $\rho_{\text{GND}} = -\frac{1}{b}\frac{d\gamma}{dx_1}$.

$$\vec{\nabla} \cdot {}^4\boldsymbol{C} : \left(\vec{\nabla}\vec{u} - \gamma\vec{e}_2\vec{e}_1\right) = \vec{0}, \qquad (1)$$

$$\dot{\gamma} = \frac{b}{B}\left|\frac{\partial\gamma}{\partial x_1}\right|\tau, \qquad (2)$$

where b is the magnitude of the Burgers vector, B is the drag coefficient and γ is the amount of plastic slip, τ is resolved shear stress.
The presented framework is able to deal with dislocation distributions as well as with a single dislocation (Figure 3). This example shows a moving single edge dislocation with Burgers vector $b = 0.25\ nm$ under shear loading and the associated normalised shear stress in the slip plane which accounts for dislocation stress and applied external shear stress.

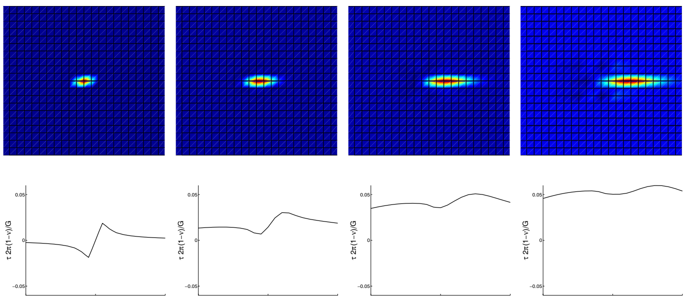


Figure 3 Single edge dislocation under shear loading (top); Normalised shear stress on slip line (bottom)

Summary

A continuum non-local model of GND density evolution has been proposed and verified for a 2D case.

Future work

The statistically stored dislocation density has to be introduced into the model as well as mobile/immobile dislocation densities. A general 3D framework has to be formulated.

References:

[1] Kosevich, A. M.: chapter in *Dislocations in solids*, Vol. 1 (1979)
[2] Kröner, E: chapter in *Physics of defects* (1981)

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