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Handle ID: http://hdl.handle.net/10985/10435

To cite this version:

Gérald FRANZ, Farid ABED-MERAIM, Tarak BEN ZINEB, Xavier LEMOINE, Marcel BERVEILLER - Strain localization analysis using a large strain self-consistent approach - 2007

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**Context of the study**

- **Mechanisms of ductility loss**
  - Plastic mechanisms of ductility loss
  - Structural origin: wrinkling, buckling
  - Material origin: localization, necking

- **Damage mechanisms of ductility loss**
  - Cavitation
  - Failure

- **Single crystal modeling**
  - **Mesoscopic scale – basic slip process**
    - Assumptions
      - Elastic-plastic behavior
      - Large strains formulation
      - Body-Centered Cubic (BCC)
      - Plastic strains only due to slip processes \(<110>\) slip direction family and \([110], (111)\) slip plane families
    - Elasticity \(\sigma = C\{d - d^e\} = \sigma_{true}(d)\)
    - Elastic-plastic tangent modulus
      \[\tau = \sigma \cdot R = R \cdot \tau' = \sigma \cdot K = K \cdot \tau'\]
    - With \(M = (\tau' + k/\beta C \cdot K)\)

- **Microscopic scale – intragranular microstructure**
  - **Assumptions**
    - The statistically stored dislocations in the cell interior, as well as the cell boundary dislocations, are represented by a single local dislocation density \(\rho\)
    - The local density of immobile dislocations stored in the wall \(\rho_{IM}\) associated with the \([110]\) plane
    - The polarity dislocations density \(\rho_{PM}\) associated with the \([110]\) plane

**Plastic anisotropy evolution**

- **Textural anisotropy**
  - (crystallographic network + morphology)
- **Structural anisotropy**
  - (intragranular microstructure)

**Scale transition**

- What is the link between local and global strain?
  - Volumetric average
    \[\sigma_V = \frac{1}{V} \int_{V} \sigma dV\]
  - Fourth order localization tensors
    \[\alpha_i = B_{ij} N_{ij}\]
  - Relation between A and B
    \[A_{ijkl} = B_{ij} B_{kl} - \delta_{ij} \delta_{kl}\]

**Ductility loss criterion**

- Assumption: the onset of localization is along a band
  (Rice, 1976)

- Field equations
  \[\nabla \cdot \varepsilon = 0\]
  \[G = \text{grad}(N)\]
  \[N = L \cdot G\]

**Microscopic validation**

- TEM micrograph

- **Polarity of dislocations walls**

**Macroscopic validation**

- Complex FLD: Uniaxial Tension prestrain (10%)
- Complex FLD: Equibiaxial Expansion prestrain (10%)
- The level of FLD after expansion prestrain seems to be realistic. The curve is shifted down and at the right in agreement with tendencies observed in literature.
- The positive side of the FLD is overestimated. This effect can be corrected by damage introduction in the model.

**Conclusions**

- Multiscale model with intragranular modeling
  - Reproduces correctly the intragranular microstructure during monotonic and sequential loading paths
  - Gives better results concerning macroscopic behavior during changing loading paths than model without intragranular modeling

- Multiscale model without intragranular modeling
  - Reproduces correctly the shape and the level of direct FLD for mild steel and dual phase
  - Reproduces the strain-path dependence of complex FLD