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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**

**Plastic mechanisms of ductility loss**
- Forming limit of sheet metal = state at which a localized strain initiates during forming.
- Ductility loss characterization using Forming Limit Diagram (FLD) developed first by Keeler (1963) and Goodwin (1968).
- Path-dependent representation.

**Metallography impact (texture, grain size, …)**

**Strain path dependence**

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

**Aims of the study**
- Ductility loss prediction for sheet metals and sequential strain paths.
- Optimization of microstructural properties for the sheet forming steels.
- Take metallurgy, microstructures, and textures into account.
- Scales transitions tools, micomechanics of plasticity, localization and damage criteria coupling with finite elements.
- Three main steps:
  - Single crystal modeling.
  - Scale transition.
  - Ductility loss criterion.

**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), (112) slip plane families.

**Elastic-plastic behavior**
- Plasticity
  \[ \tau = \sigma : \dot{\varepsilon} - \dot{\varepsilon}^p = \mathbf{C} d - \dot{\varepsilon}^p \]
- Elastic-plastic tangent modulus
  \[ \dot{\varepsilon}^p = \frac{\tau}{E} \]

**Microscopic scale – intragranular microstructure**
- 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 \( \rho^{\text{wall}} \) associated with the \( \langle 110 \rangle \) plane.
- The polarity dislocations density \( \rho^{\text{pol}} \) associated with the \( \langle 110 \rangle \) plane.

**Scale transition**
- What is the link between local and global strain?
  \[ \Sigma, \dot{\varepsilon} \]
- Volumetric average
  \[ G = \frac{1}{V} \int \sigma \, dV \]
- Fourth order localization tensors
  \[ \alpha_{ijkl} S_{ij} \]
- Relation between A and B
  \[ \alpha_{ijkl} = B_{ijkl} + \alpha_{ijkl} \]

**Ductility loss criterion**
- Assumption: the onset of localization is along a band (Rice, 1976)
  \[ \text{Field equations} \]
  \[ \text{Boundary conditions} \]
  \[ \text{Ellipticity loss} \]

**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.

**Conclusions**
- 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.