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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**

- Cavities
- Failure

**Strain path dependence**

- Forming limit diagram
- Plastic anisotropy evolution

**Aims of the study**

- Ductility loss prediction for mild steel and sequential strain paths
- Optimization of microstructural properties for sheet forming steels
- Steel behaviour during sheet forming
- Hardening, complex loads, instabilities, anisotropy
- Three main steps:
  - Single crystal modeling
  - Scale transition
  - Ductility loss criterion

**Scale transition**

- **N** × **L** × **G
  - Field equations:
    \( \text{div}(\mathbf{N}) = 0 \)
  - \( G = \text{grad}(V) \)
  - \( N = L \times G \)

**Ductility loss criterion**

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

**Single crystal modeling**

**Mesoscopic scale – basic slip process**

- **Plasticity**
  - \( \tau = \sigma \cdot R \)
- **Elastic-plastic tangent modulus**
  - \( \tilde{E} = \frac{1}{3} \left( m_{ijkl} \right) k_R^2 \)

**Microscopic scale – intragranular microstructure**

- **Microscopic validation**
  - TEM micrograph

**Microscopic validation**

- Intensity of dislocations walls
- Polarity of dislocations walls

**Forming Limit Diagrams**

- Direct FLD
- Complex FLD: Equibiaxial Expansion prestrain (10%)
- Complex FLD: Uniaxial Tension prestrain (10%)

**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

**Plastic anisotropy evolution**

- **TEM** (Parkes, 2002)
- **Structural anisotropy** (intragranular microstructure)

- **Textures anisotropy** (crystallographic network + morphology)

**Strain localization analysis using a large strain self-consistent approach**

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