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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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STRAIN LOCALIZATION ANALYSIS USING A LARGE STRAIN SELF-CONSISTENT APPROACH

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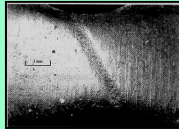
Context of the study

Mechanisms of ductility loss

Plastic mechanisms of ductility loss

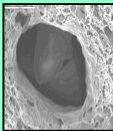


Structural origin:
wrinkling, buckling

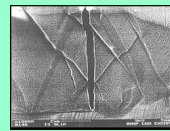


Material origin:
localization, necking

Damage mechanisms of ductility loss



Cavities

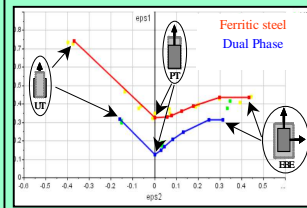


Failure

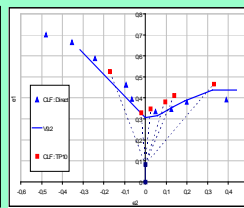
Forming Limit Diagram (FLD)

- 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

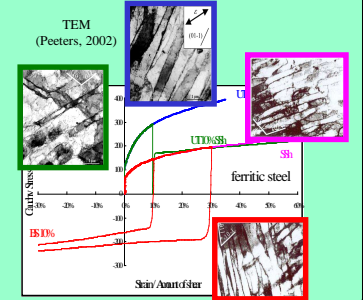
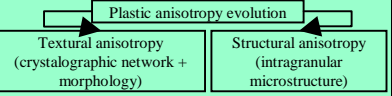
Metallurgy impact (texture, grain size, ...)



Strain path dependence



Plastic anisotropy evolution



Aims of the study

- Ductility loss prediction for various loading paths and sequential strain paths
- Optimization of microstructural properties for the sheet forming steels

Take metallurgy, mechanisms, microstructure and textures into account

Scales transitions tools, micromechanics of plasticity, localization and damage criteria, coupling with finites elements

Steel behaviour during sheet forming: hardening, complex loads, instabilities, anisotropy

- Three main step :
 - 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)

Elasticity $\sigma = C : (d - d^e) - \text{arccel}(d)$

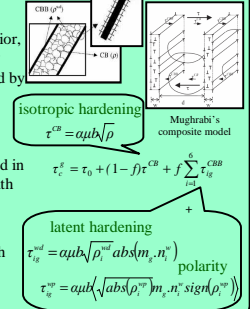
Plasticity $d^e = R^s \gamma^s$

Elastic-plastic tangent modulus $\dot{n} = l : g$

$$\begin{aligned} \dot{\gamma}^s &= \dot{\sigma} : R^s \\ \dot{w}^s &= S^s \dot{\gamma}^s \\ \dot{n} &= l : g \\ \dot{n} &= \begin{bmatrix} C_{\text{slip}} - \frac{1}{2}(\delta_{ij}\sigma_{ij} + \delta_{ij}\sigma_{ij}) - \frac{1}{2}(\sigma_{ij}\delta_{ij} - \sigma_{ij}\delta_{ij}) \\ -[C_{\text{slip}} R_{ij}^s + S_{ij}^s \sigma_{ij} - \sigma_{ij} S_{ij}^s] M_{ij} k^s R_{ij}^s (C_{\text{slip}} - \sigma_{ij} \delta_{ij}) \\ \text{with } M^{ij} = (\delta^{ij} + k^s R_{ij}^s C_{\text{slip}} R_{ij}^s)^{-1} \end{bmatrix} \end{aligned}$$

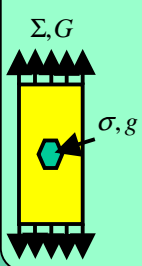
Microscopic scale – intragranular microstructure

- The statistically stored dislocations in the cell interior, as well as the cell boundary dislocations, are represented by a single local dislocation density ρ
- The local density of immobile dislocations stored in the wall $\rho^{(WB)}$ associated with the {110} plane
- The polarity dislocations density $\rho^{(WP)}$ associated with the {110} plane



Scale transition

What is the link between local and global strain?



$$\dot{N}_{ij} = \frac{1}{V} \int_V \dot{n}_{ij} dV$$

$$G_{ij} = \frac{1}{V} \int_V g_{ij} dV$$

Fourth order localization tensors

$$\dot{n}_{ij} = B_{ijkl} \dot{N}_{kl} \quad I_{ijkl}^{\text{eff}} = l_{ijmn} A_{mnlk}$$

$$g_{ij} = A_{ijkl} G_{kl}$$

Relation between A and B

$$A_{ijkl} = l_{ijmn}^{-1} B_{mnpq} I_{pqkl}^{\text{eff}}$$

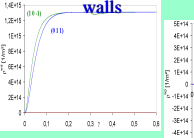
Microscopic validation

TEM micrograph

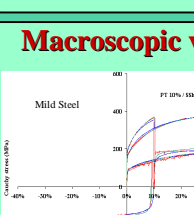


Longitudinal plane view TEM micrograph in a grain with initial orientation (43.3°, 127.8°, -42.4°) after a reverse test of 30% simple shear with SD parallel RD and SPN parallel to TD (Nesterova et al., 2001)

Intensity of dislocations walls

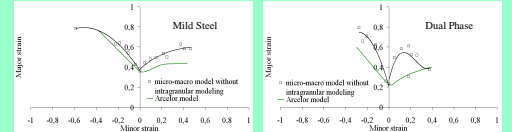


Polarity of dislocations walls



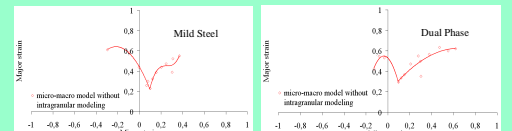
Forming Limit Diagrams

Direct FLD



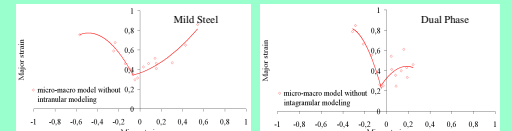
- The positive side of the FLD is overestimated. This effect can be corrected by damage introduction in the model

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

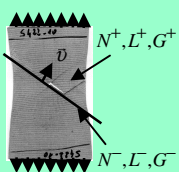
Complex FLD: Uniaxial Tension prestrain (10%)



- FLD is shifted at the left in agreement with tendencies observed in literature but the level of the lower point of the FLD is lower

Ductility loss criterion

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



Field equations

$$\text{div}(\dot{N}^T) = 0$$

$$G = \text{grad}(V)$$

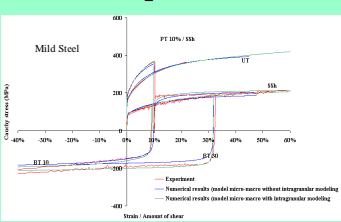
$$\dot{N} = L : G$$

Boundary conditions

Ellipticity loss

$$\det(\mathbf{u}L\mathbf{v}) = 0$$

Macroscopic validation



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