Ratchetting

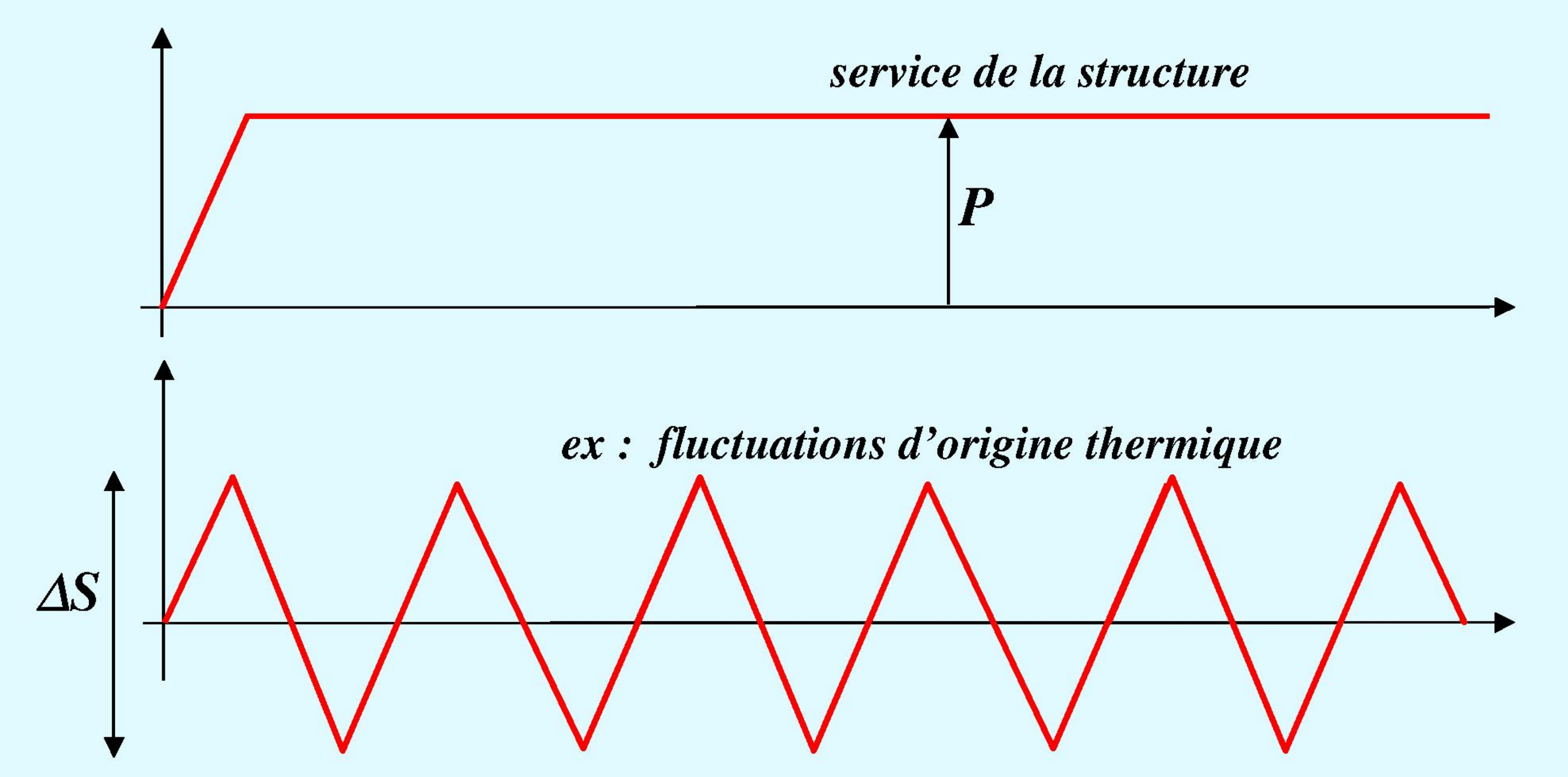
- **Onedimensional ratchetting**
- **Twodimensional ratchetting**
- **Response of unified models**
- **Response of 2M1C model**
- **Response of polycrystalline models**

–Still an open problem–

Ratchetting effects

Primary + secondary loadings on a structure

(pressure vessels, structures submitted to TMF loading)



Asymptotic behavior under cyclic loading

- *Elastic shakedown =*

  Elastic behavior, maybe after initial plastic strain,

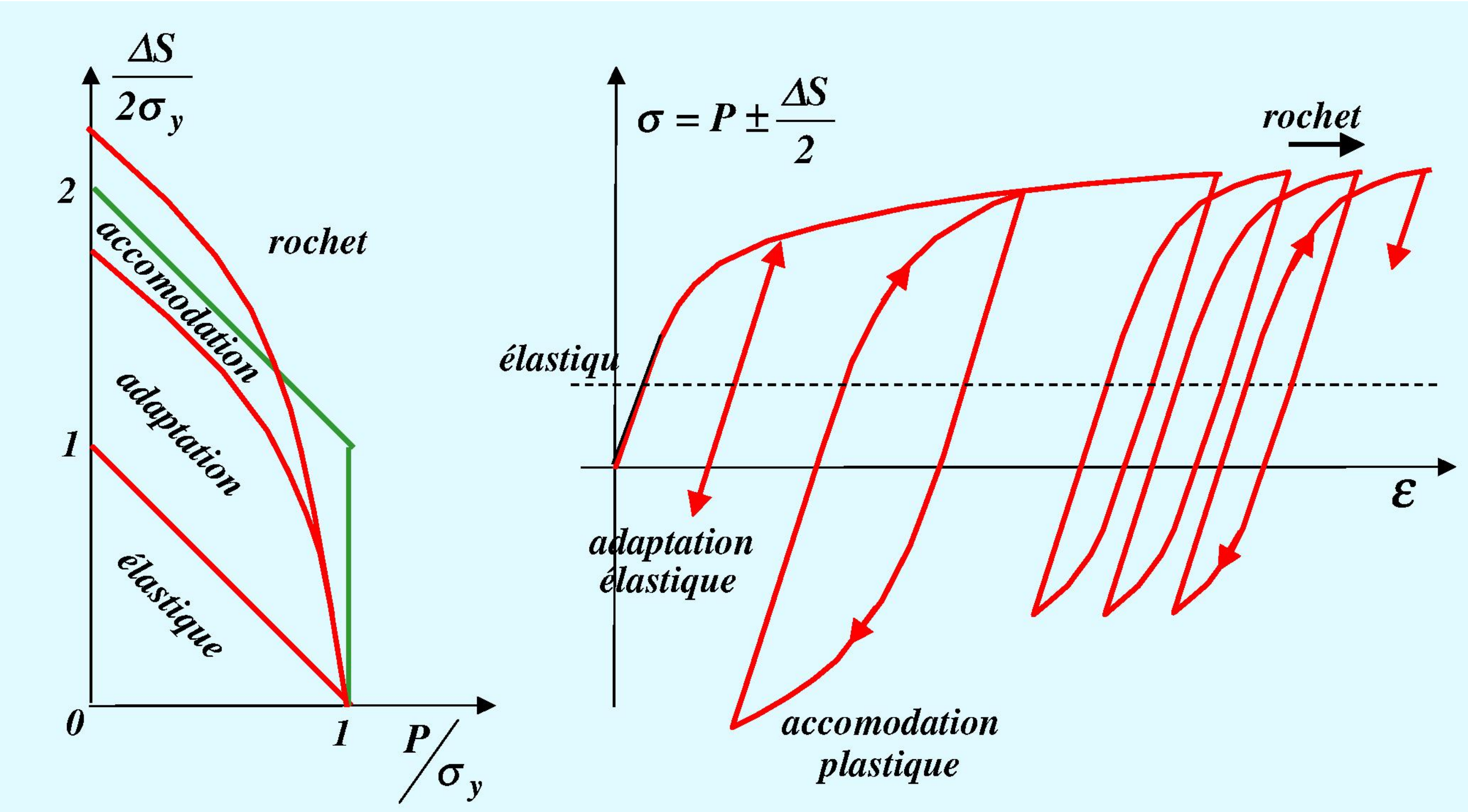
- *Plastic shakedown =*

  Open loop, with a periodic plastic loading between two fixed values

- *Ratchetting =*

  Accumulation of deformation, leading to failure by excessive deformation

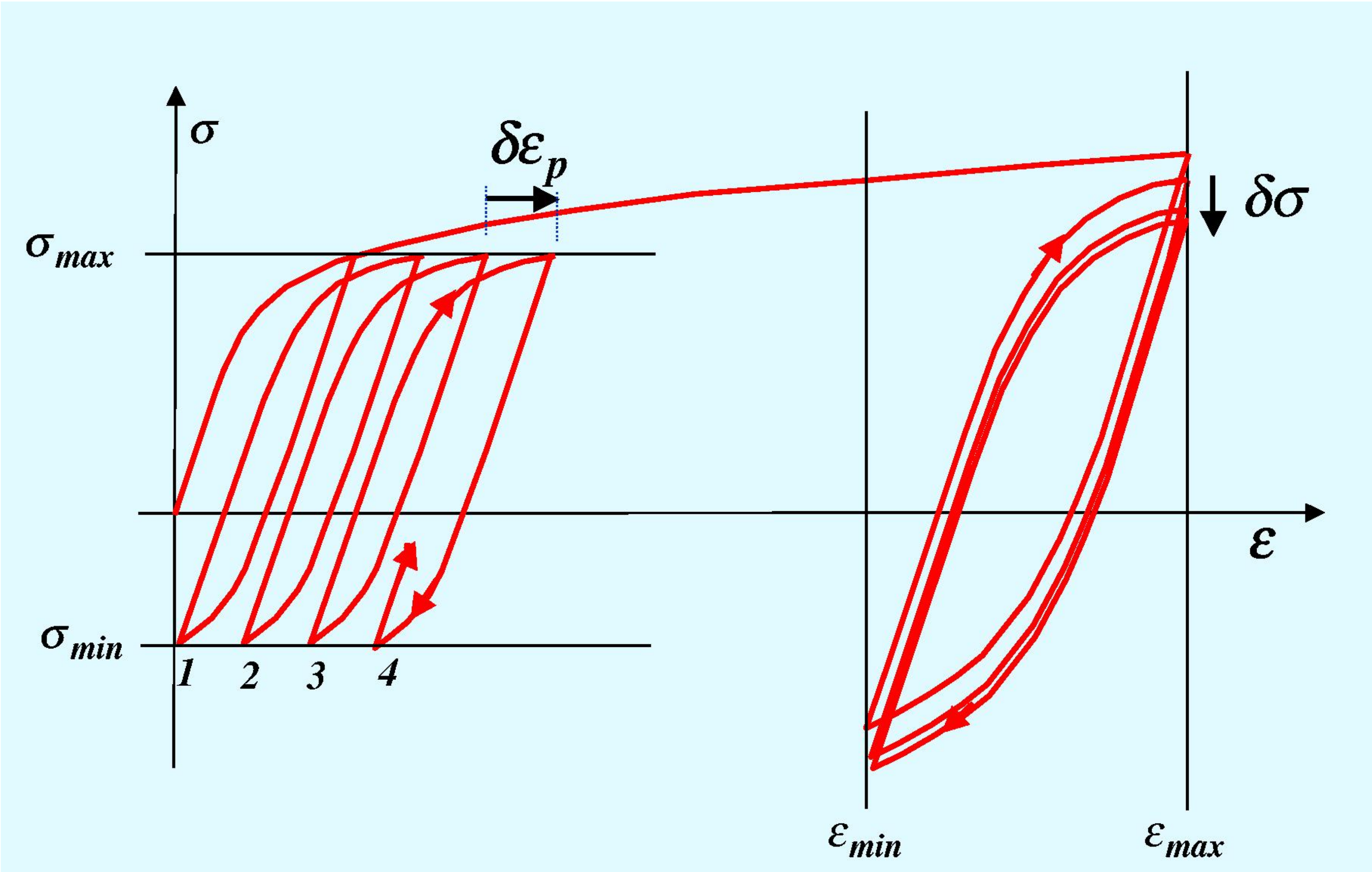
Onedimensional ratchetting



Bree diagram

Elastic/plastic shakedown, ratchetting

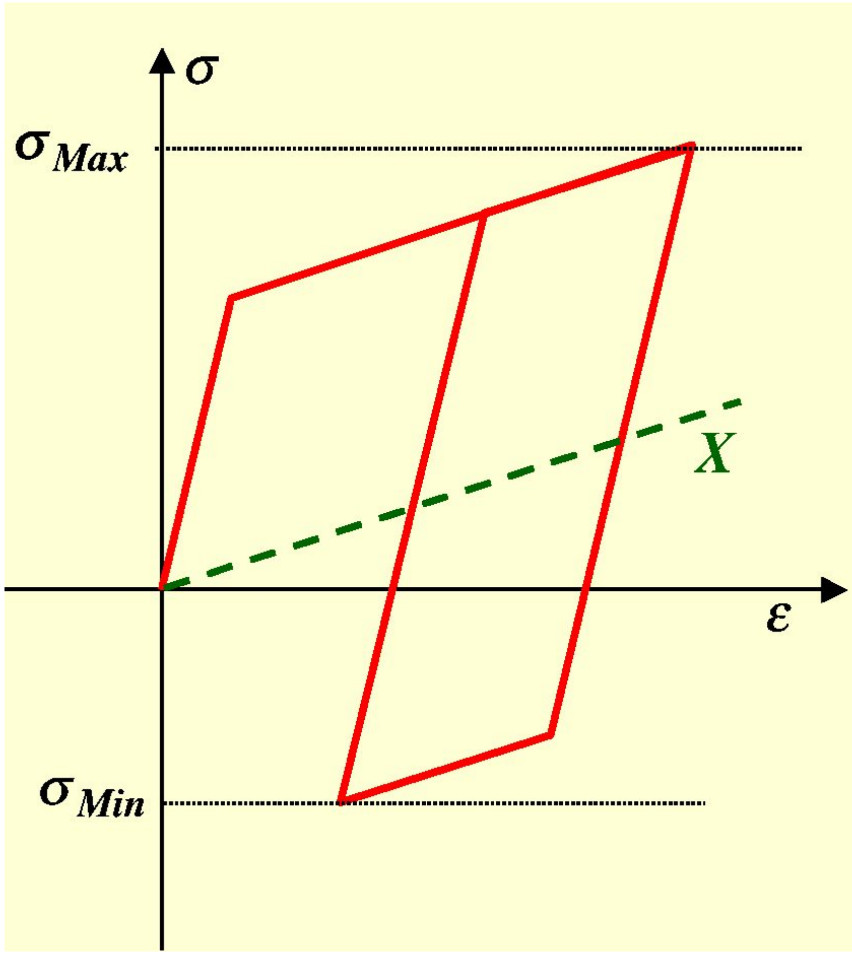
Ratchetting and mean stress relaxation



Ratchetting

Mean stress relaxation

Response of linear kinematic hardening for 1D loading



- Criterion :

$$|\sigma - X| - \sigma_y = 0$$

- Tension going branch :

$$\sigma = X + \sigma_y = 0$$

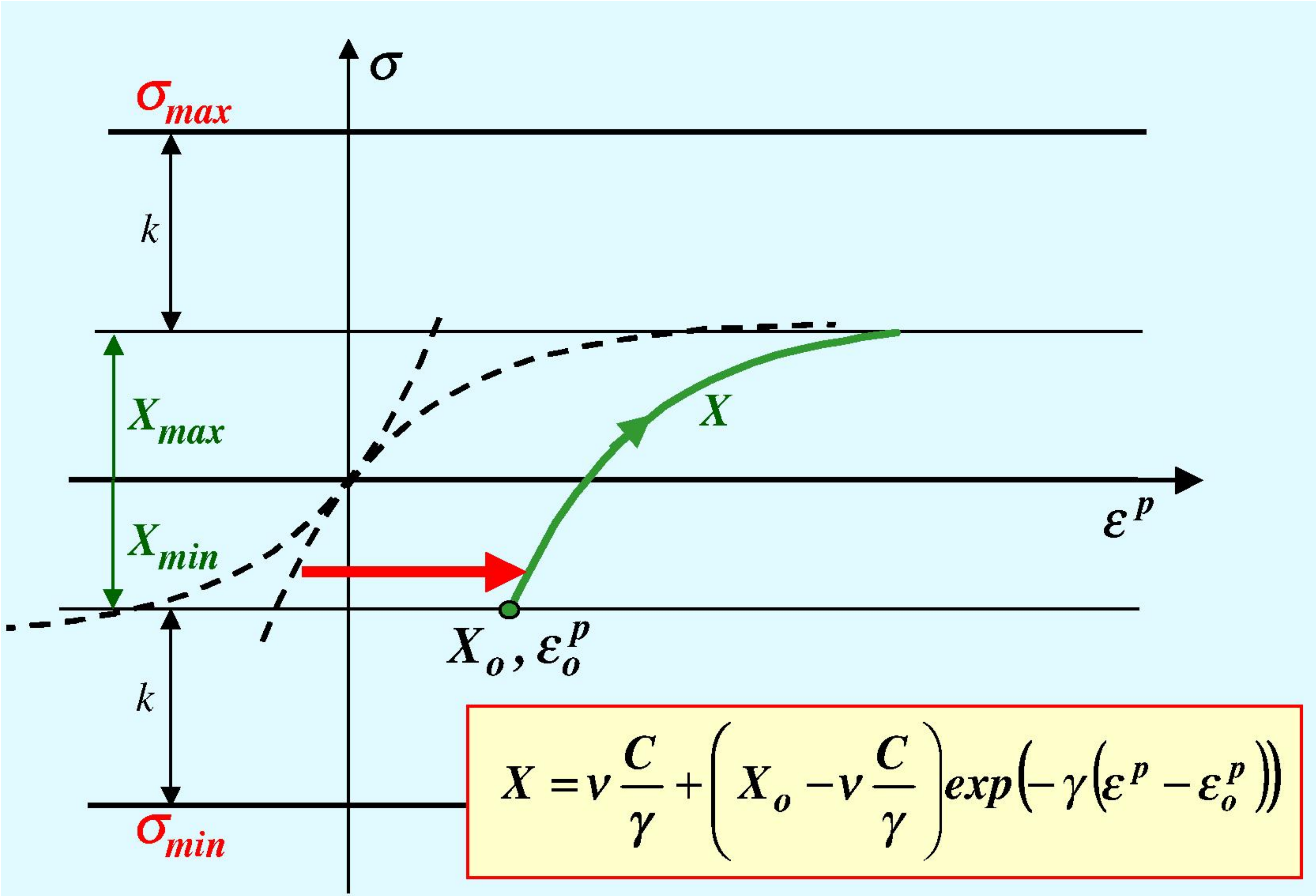
- Compression going branch :

$$\sigma = X - \sigma_y = 0$$

- *Same behavior for any cycle*

Linear kinematic hardening does not *represent any ratchetting*

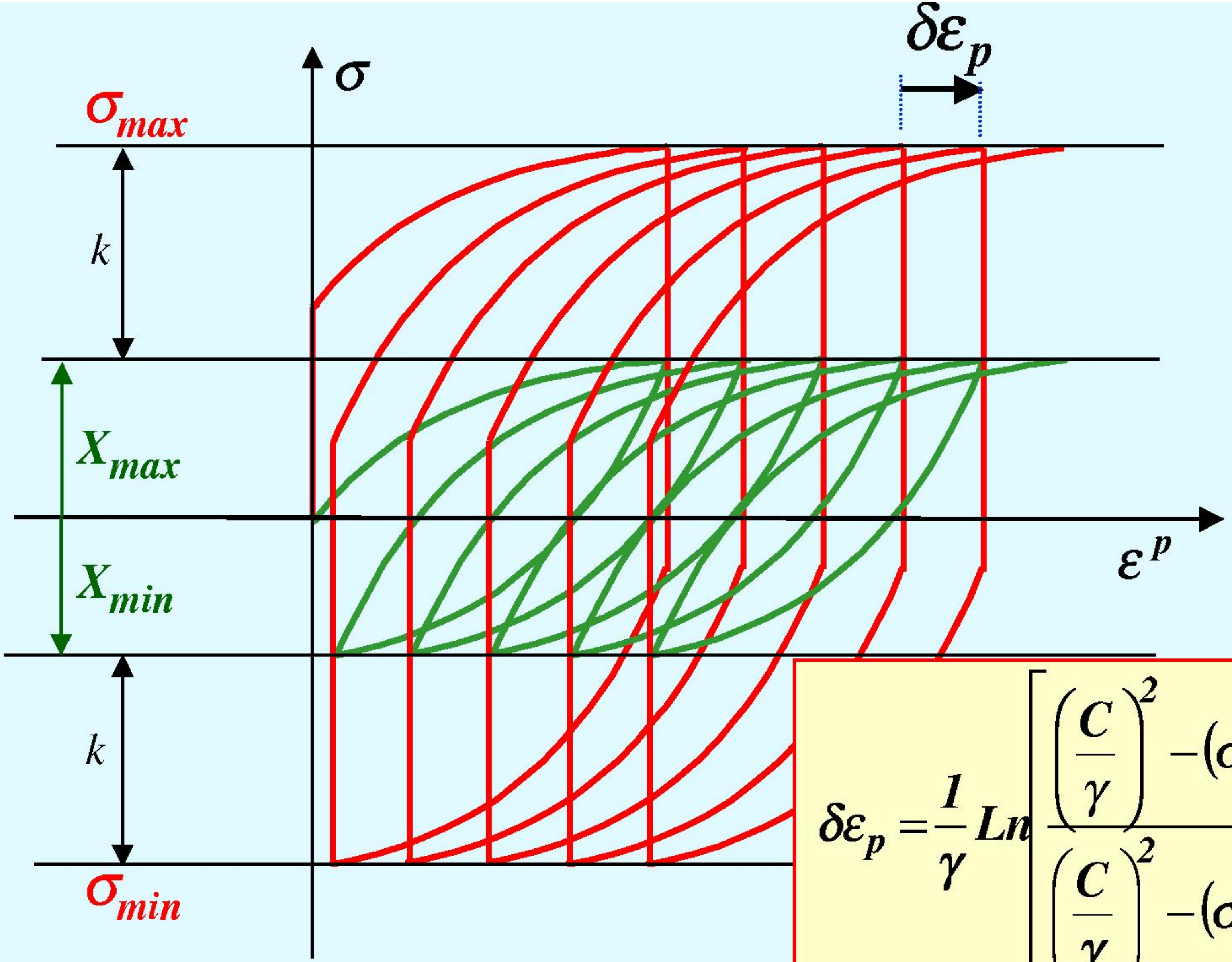
Response of non linear kinematic hardening



$$X = \nu \frac{C}{\gamma} + \left(X_o - \nu \frac{C}{\gamma} \right) exp\left(-\gamma\left(\varepsilon^p - \varepsilon_o^p\right)\right)$$

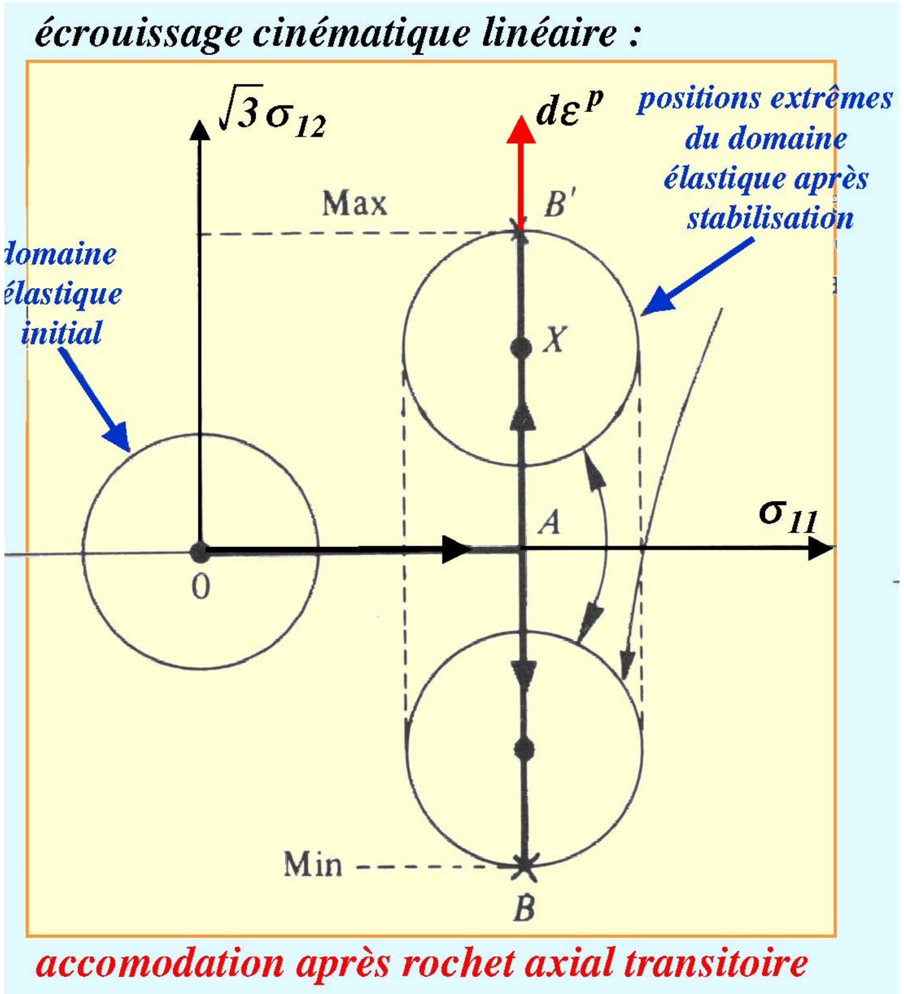
Linear kinematic hardening predict always ratchetting (or elastic shakedown)

Modeling of ratchetting with nonlinear kinematic hardening



$$\delta\varepsilon_p = \frac{1}{\gamma} Ln \left[\frac{\left(\frac{C}{\gamma}\right)^2 - (\sigma_{min} + k)^2}{\left(\frac{C}{\gamma}\right)^2 - (\sigma_{max} - k)^2} \right]$$

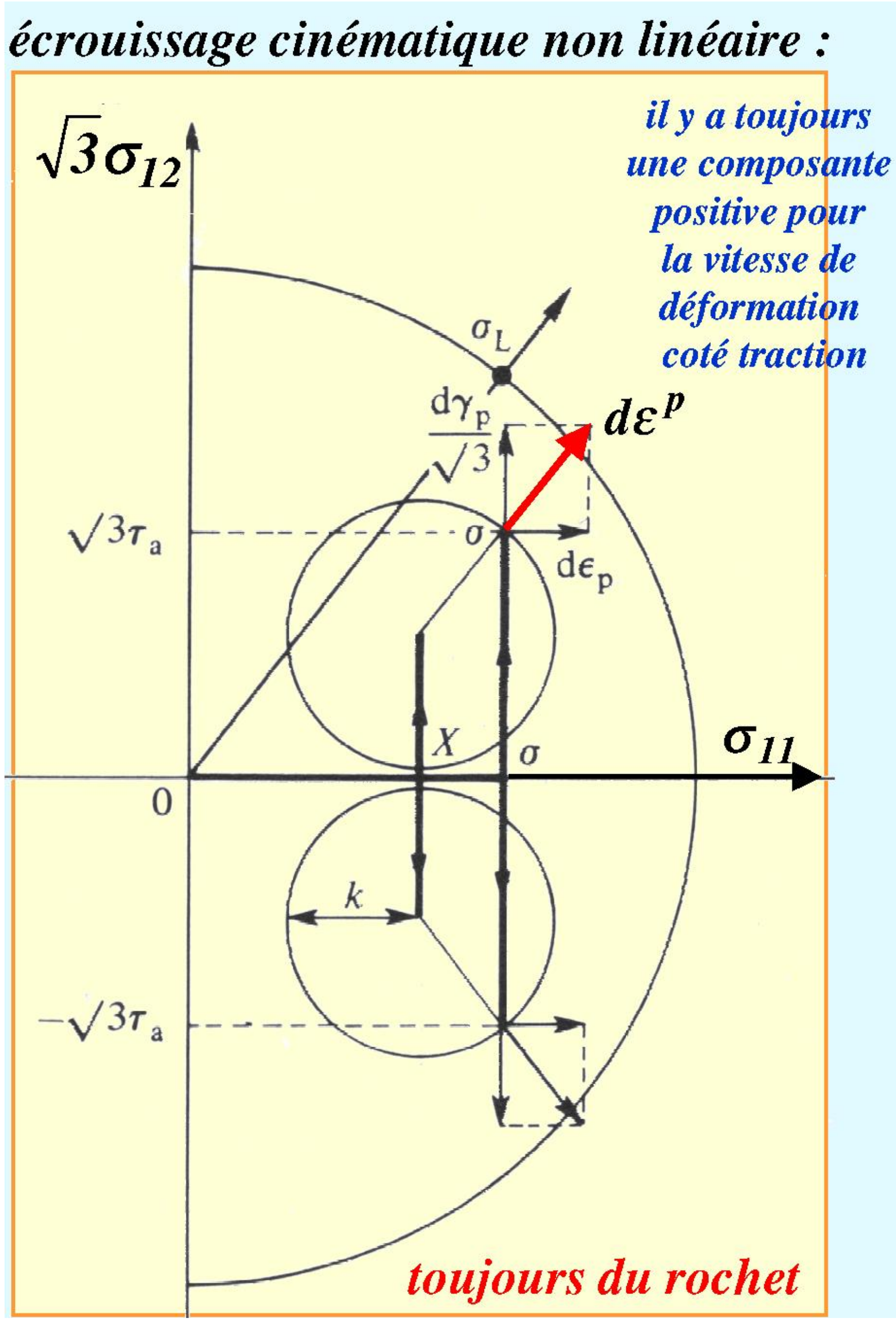
Tension-shear loading with linear kinematic hardening



$$\dot{X}_{11} = (2/3)C\dot{\varepsilon}^p_{11}$$

- The axial component of $\underset{\sim}{\boldsymbol{X}}$ increases if there is an axial component of plastic strain
- Steady state when $\dot{\varepsilon}^p_{11} = 0$, the value of the axial component of $X = (3/2)X_{11}$ reaches the value of the applied stress σ_{11}

Tension-shear loading with non linear kinematic hardening



$$\dot{X}_{11} = (2/3)C\dot{\varepsilon}^p_{11} - DX_{11}\dot{p}$$

$$\dot{p} = \left(\dot{X}^2_{11} + (4/3)\dot{X}^2_{12}\right)^{1/2}$$

- Since $|\dot{X}_{11}| < \dot{p}$, the axial component of $\underset{\sim}{\boldsymbol{X}}$ is limited be the fading memory term
- Steady state of X_{11} such as $|X| < |\sigma_{11}|$

Behavior of the classical model versus *ratchetting*

- *No ratchetting* with linear kinematic hardening
- *Too much ratchetting* with nonlinear kinematic hardening
- Possible improvements or alternative solutions:
  - ⋆ Introduce a threshold in nonlinear kinematic model
  - ⋆ Use multimechanism models (like 2M1C)
  - ⋆ Use model with scale transition (like β-rule)

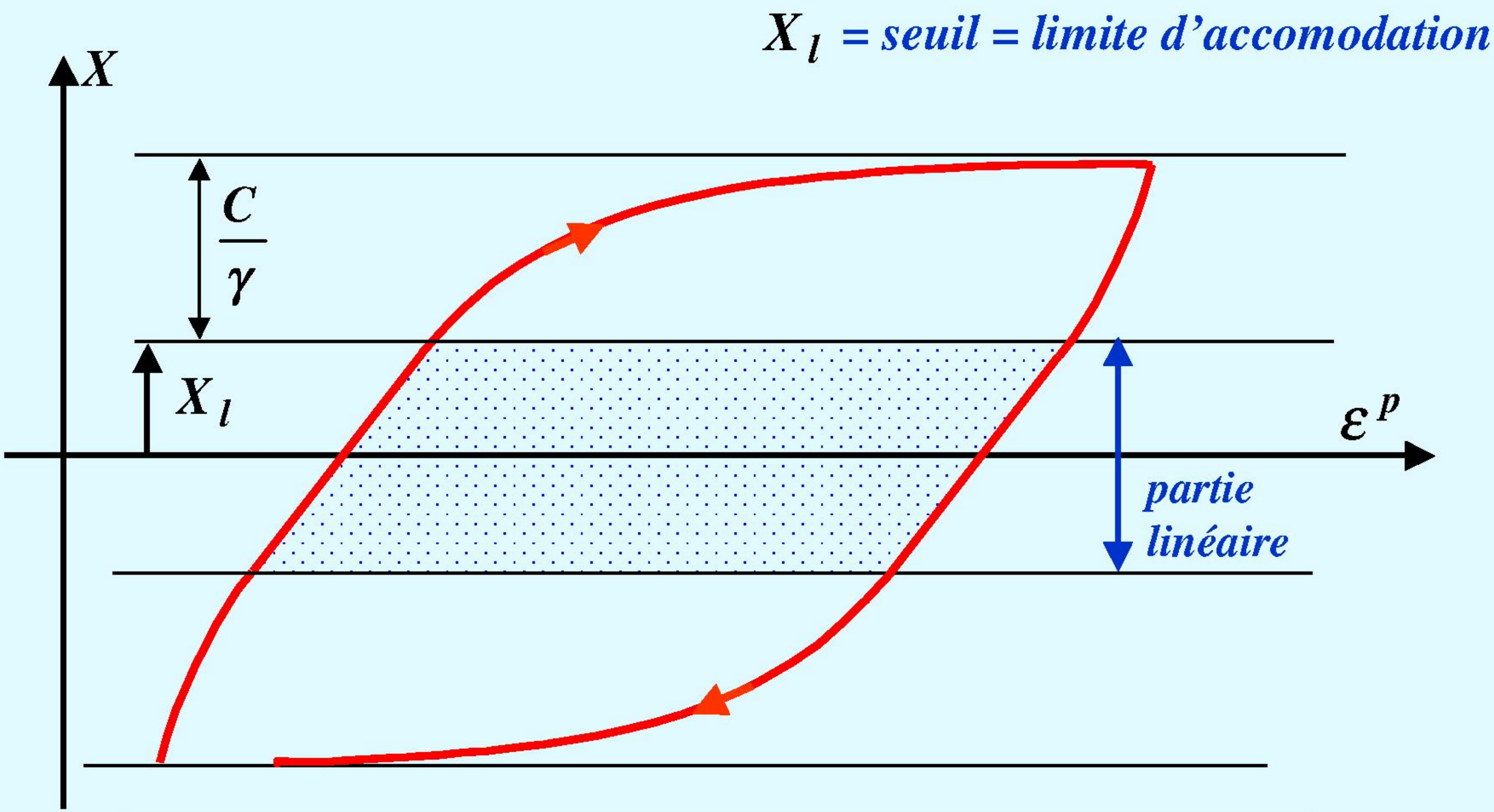
Nonlinear kinematic model with a threshold

- *For a low dissymmetry:*
  the model should predict elastic shakedown → linear kinematic rule
- *For a larger dissymmetry:*
  the model should predict ratchetting → nonlinear kinematic rule
- Threshold suppressing the fading memory term for low dissymmetry

$$\dot{\underset{\sim}{\boldsymbol{X}}} = \frac{2}{3} C \dot{\underset{\sim}{\boldsymbol{\varepsilon}}}^p - D \frac{(J(\underset{\sim}{\boldsymbol{X}}) - X_l)}{J(\underset{\sim}{\boldsymbol{X}})} \underset{\sim}{\boldsymbol{X}} \dot{p}$$

with $J(\underset{\sim}{\boldsymbol{X}}) = \left((3/2)\underset{\sim}{\boldsymbol{X}} : \underset{\sim}{\boldsymbol{X}}\right)^{1/2}$, and X_l a new material coefficient

Onedimensional response for NLK model with a threshold

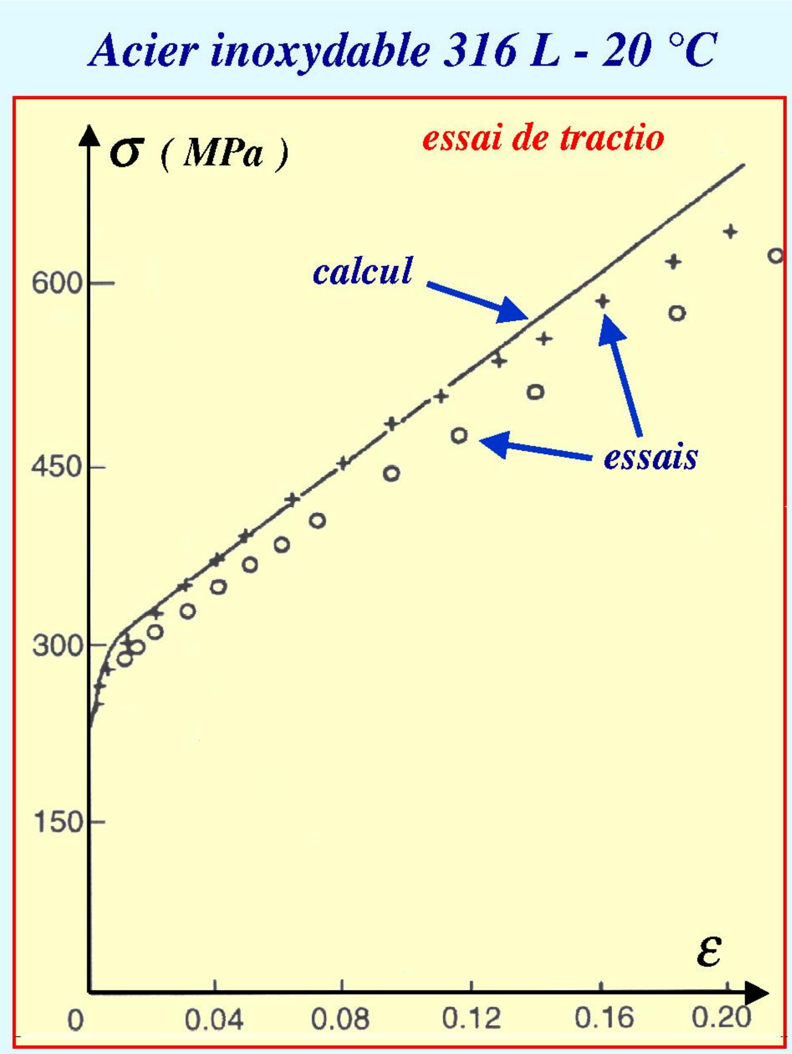


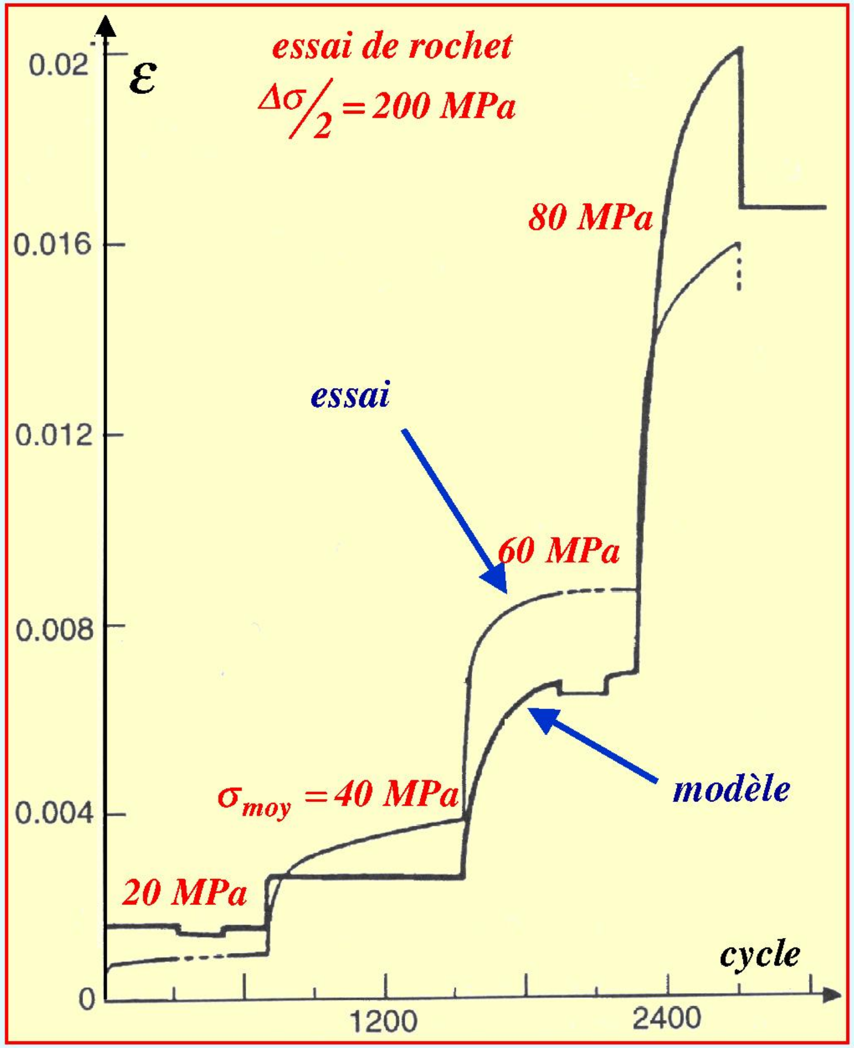
$$d\underline{X} = \frac{2}{3} C\, d\underline{\varepsilon}^p - \gamma \left\langle \|X\| - X_l \right\rangle \frac{\underline{X}}{\|X\|} dp$$

Modeling of 1D ratchetting on 316 stainless steel

Tests with constant stress amplitude, varying mean stress

No ratchetting for low mean stress, ratchetting for higher mean stress

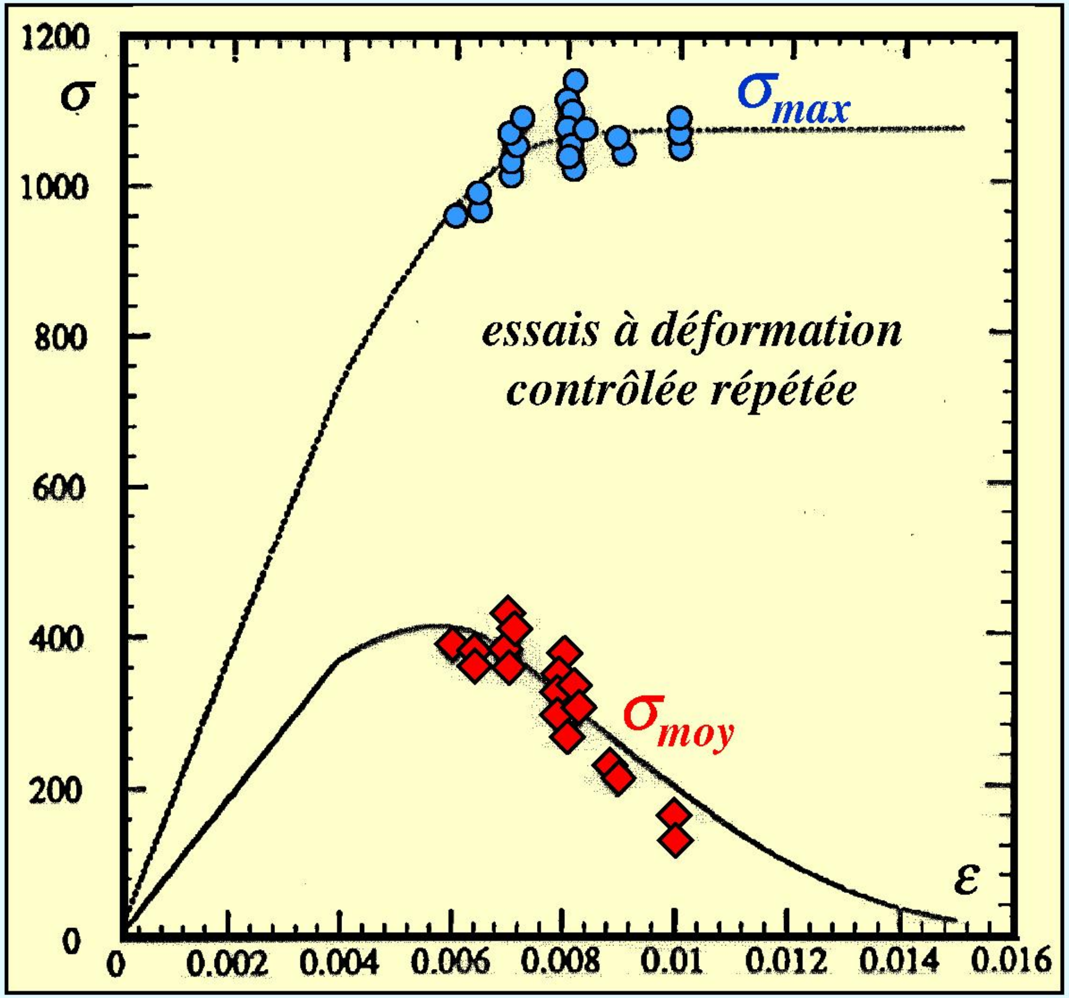




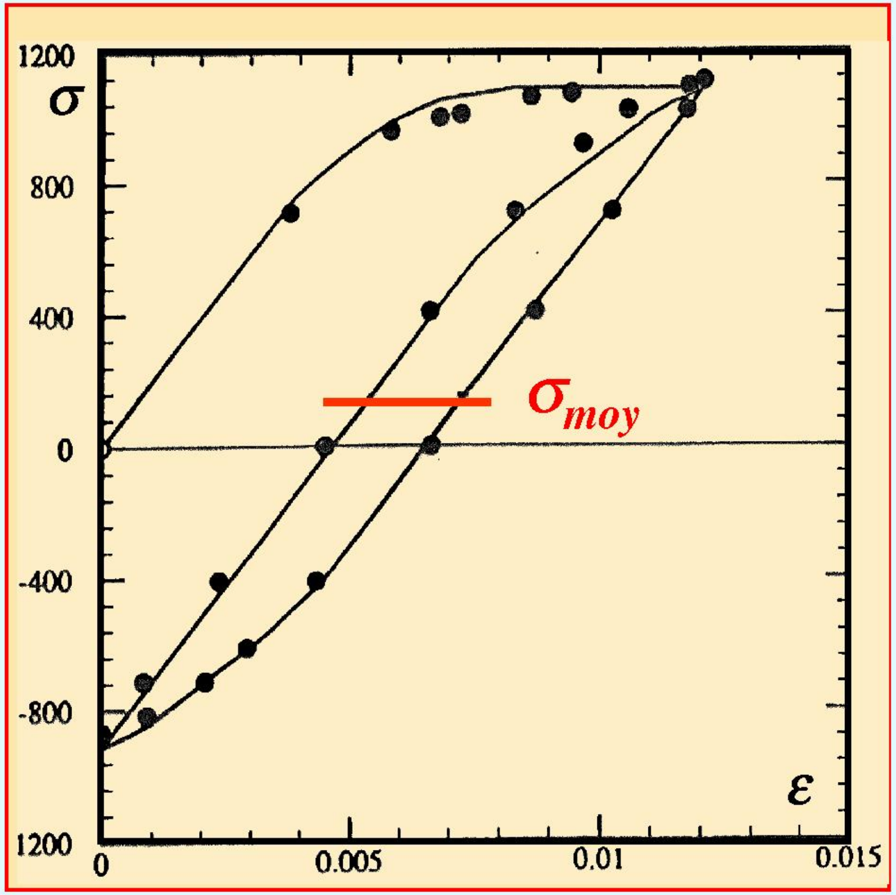
Chaboche (1991)

Modeling of mean stress relaxation for NLK model with a threshold

Test under strain control 0–ε_{max}

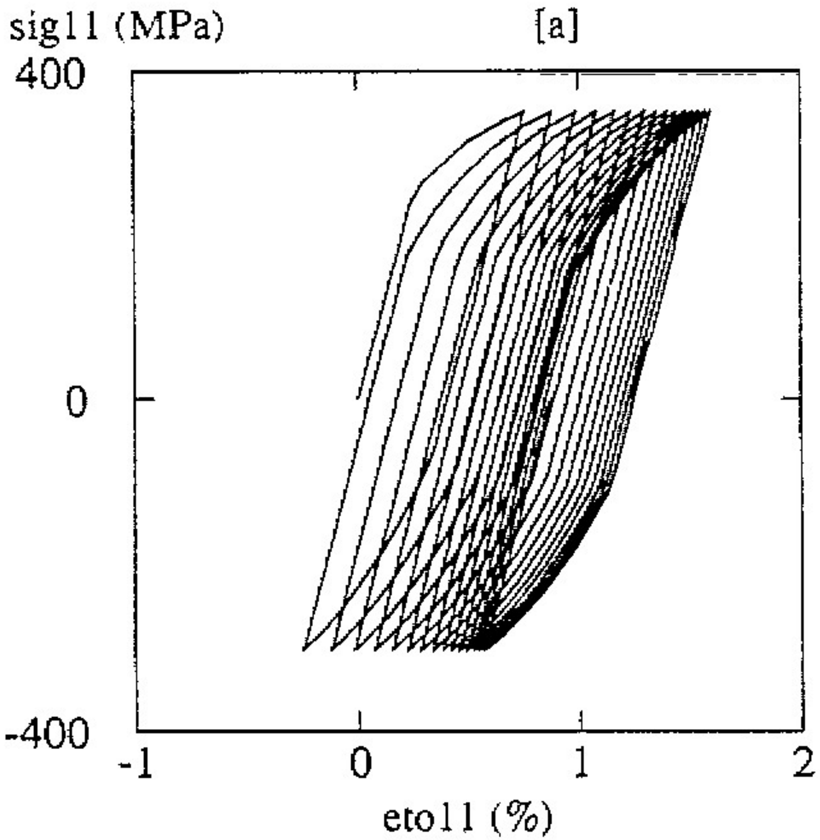


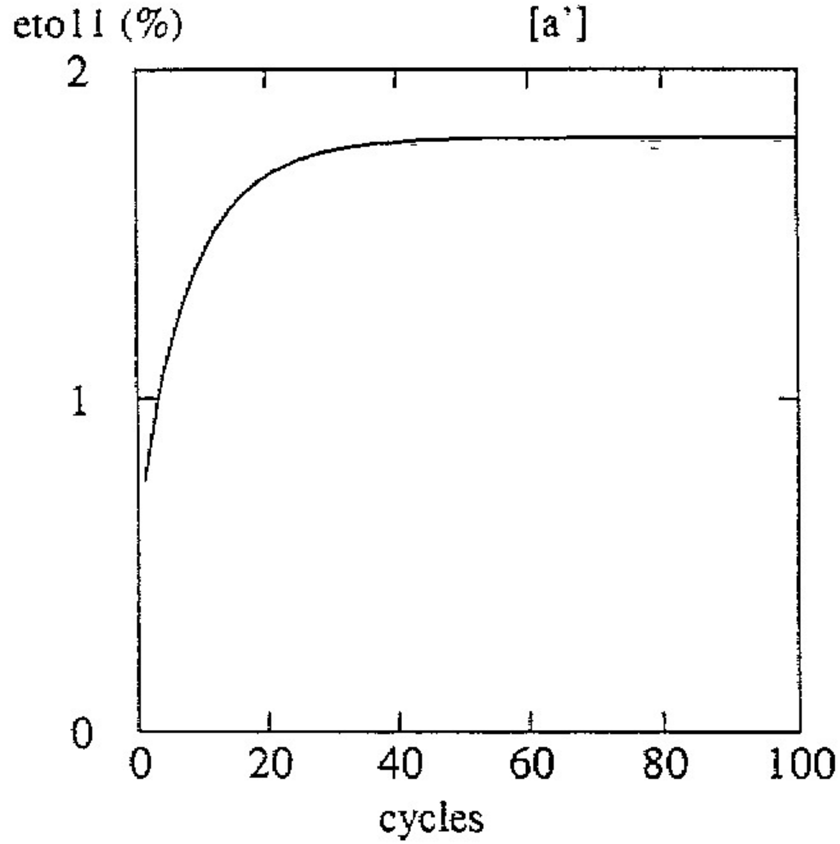
superalliage pour disques N18
550 °C



Chaboche (1991)

Onedimensional response for 2M1C model with a regular matrix

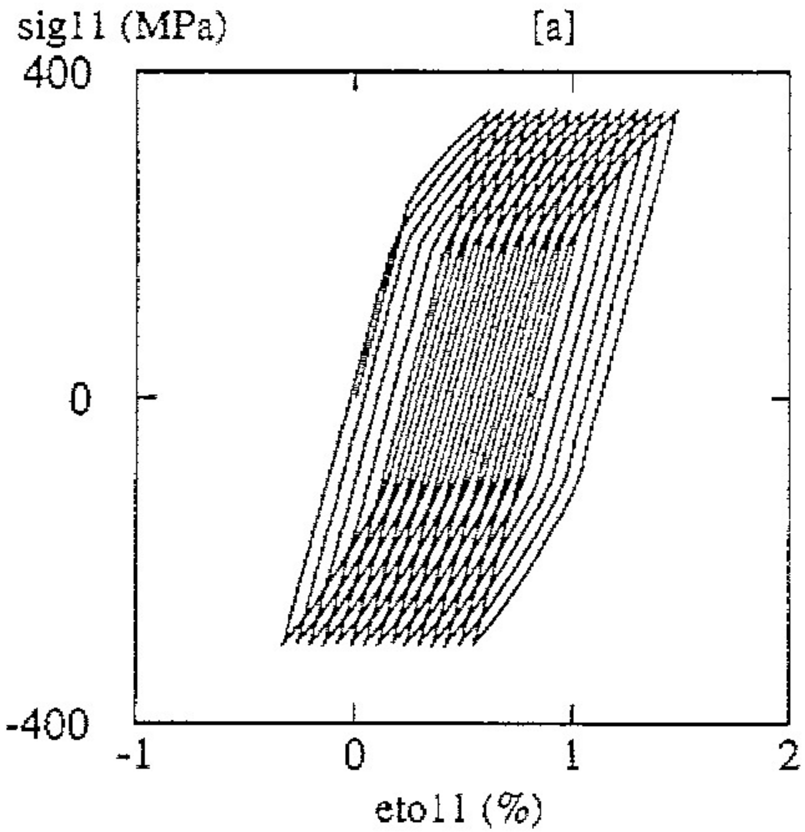


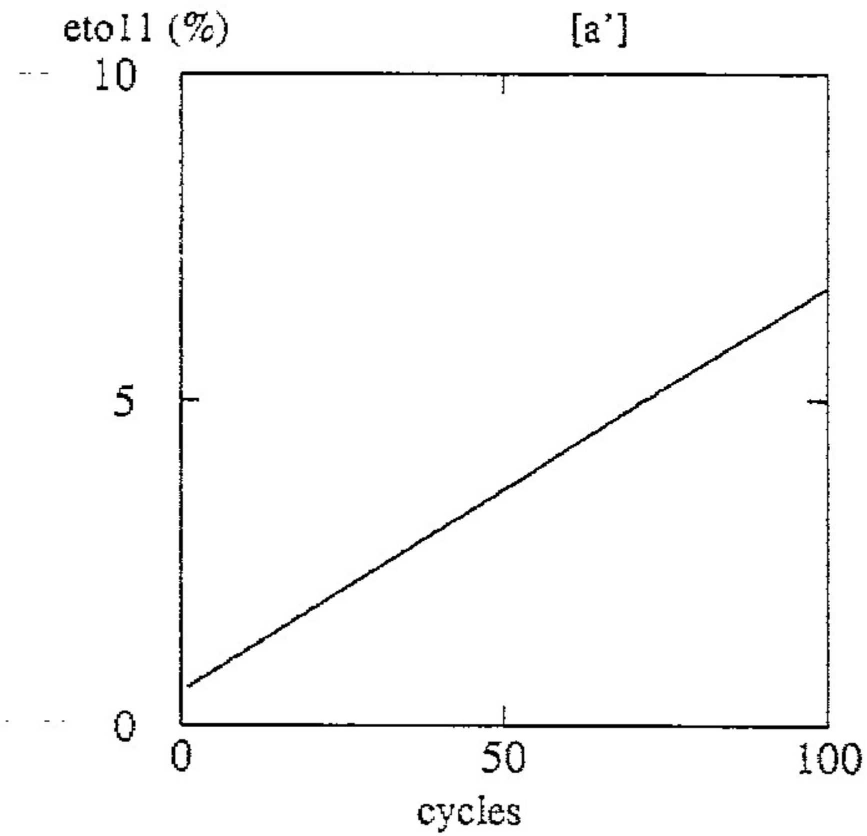


$$C_{11}C_{22} - C_{12}^2 \neq 0$$

No ratchetting observed

Onedimensional response for 2M1C model with a singular matrix

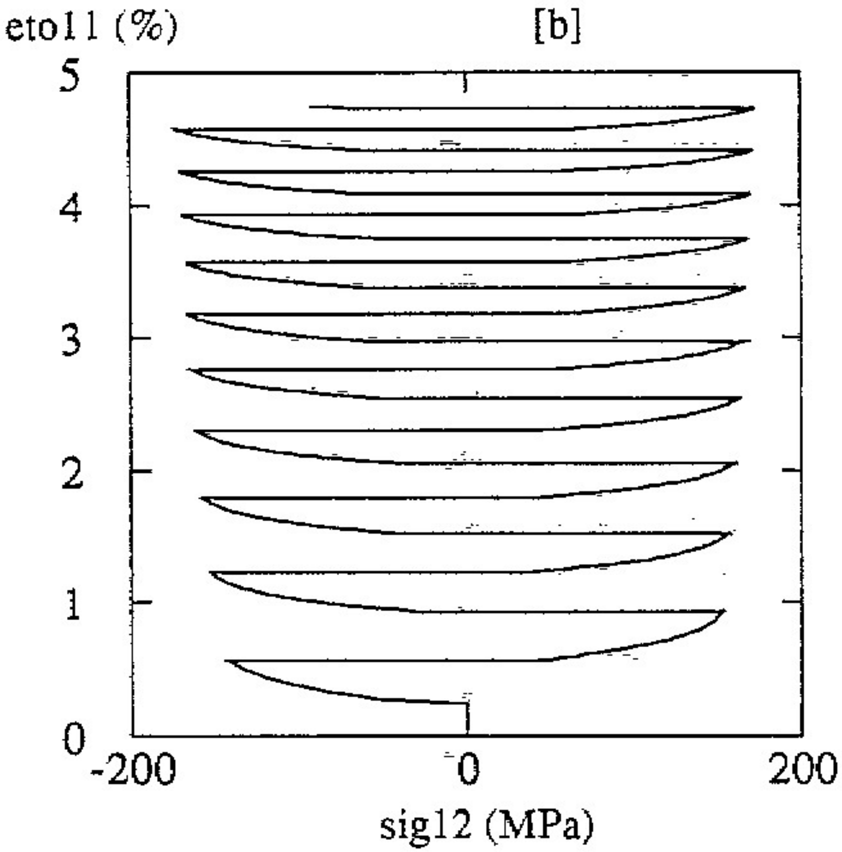


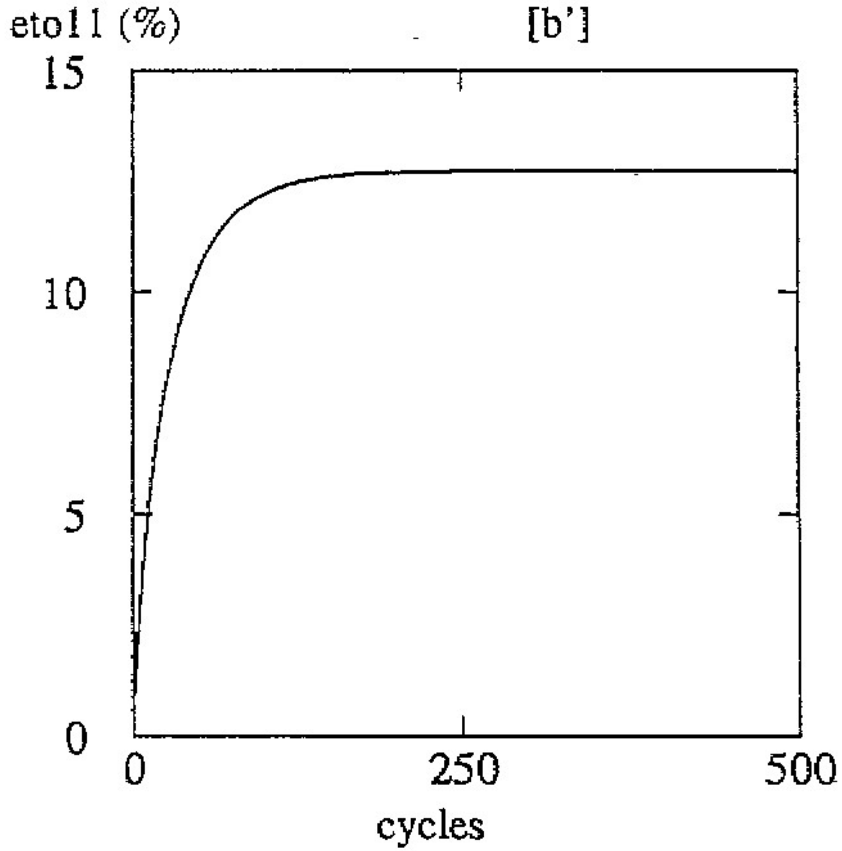


$$C_{11}C_{22} - C_{12}^2 = 0$$

Presence of ratchetting

Twodimensional response for 2M1C model with a regular matrix

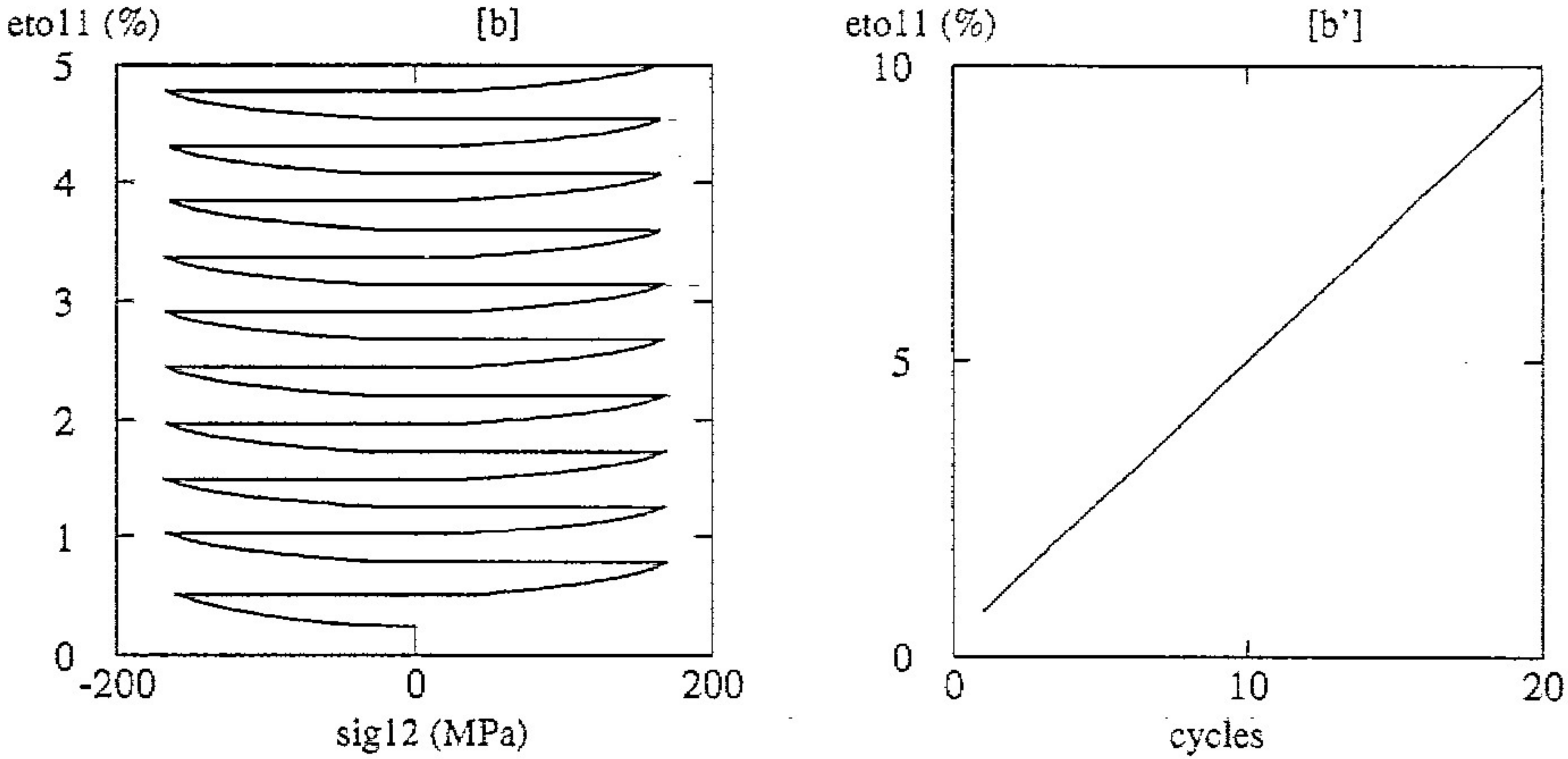




$$C_{11}C_{22} - C_{12}^2 \neq 0$$

No ratchetting observed

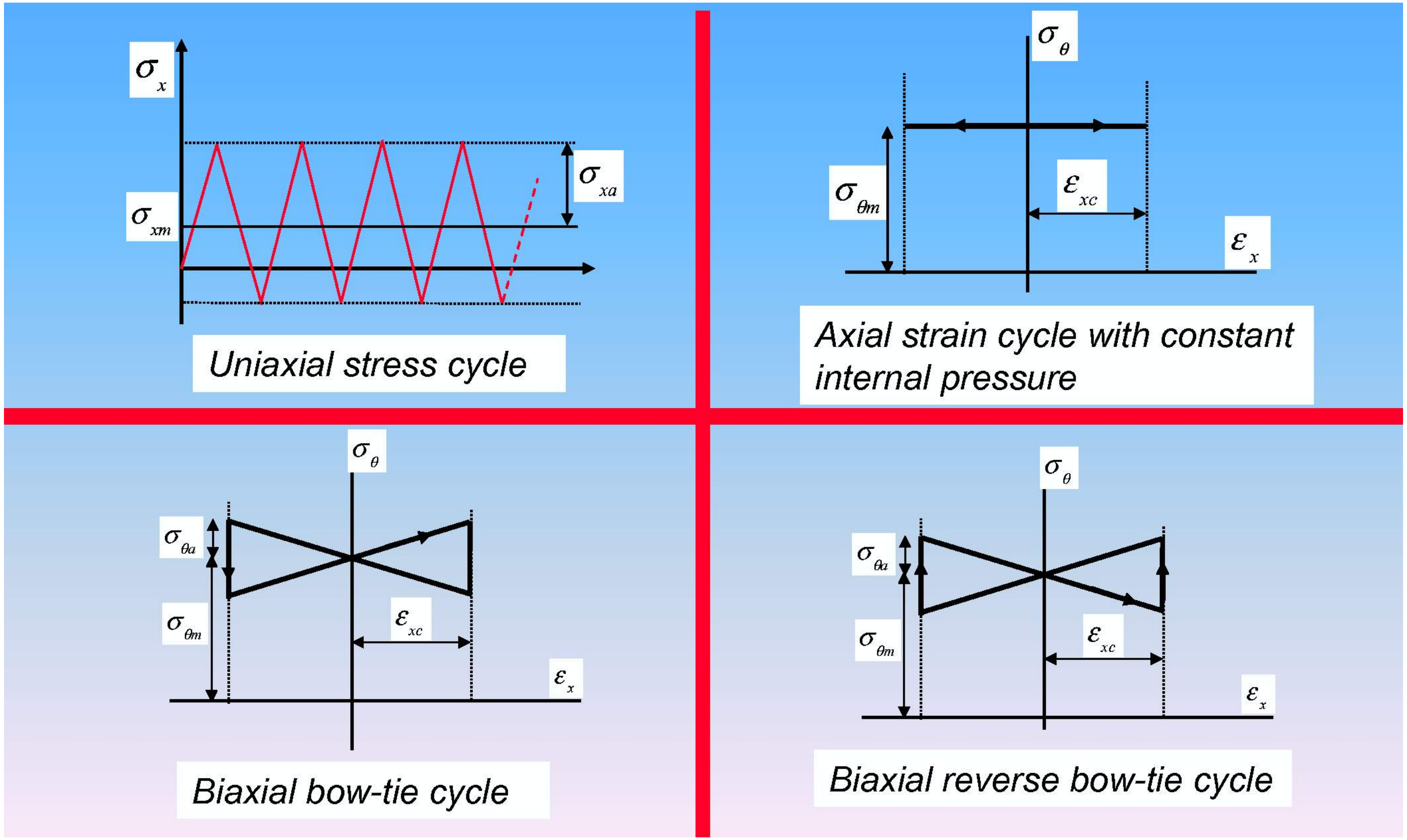
Twodimensional response for 2M1C model with a singular matrix



$$C_{11}C_{22} - C_{12}^2 = 0$$

Presence of ratchetting

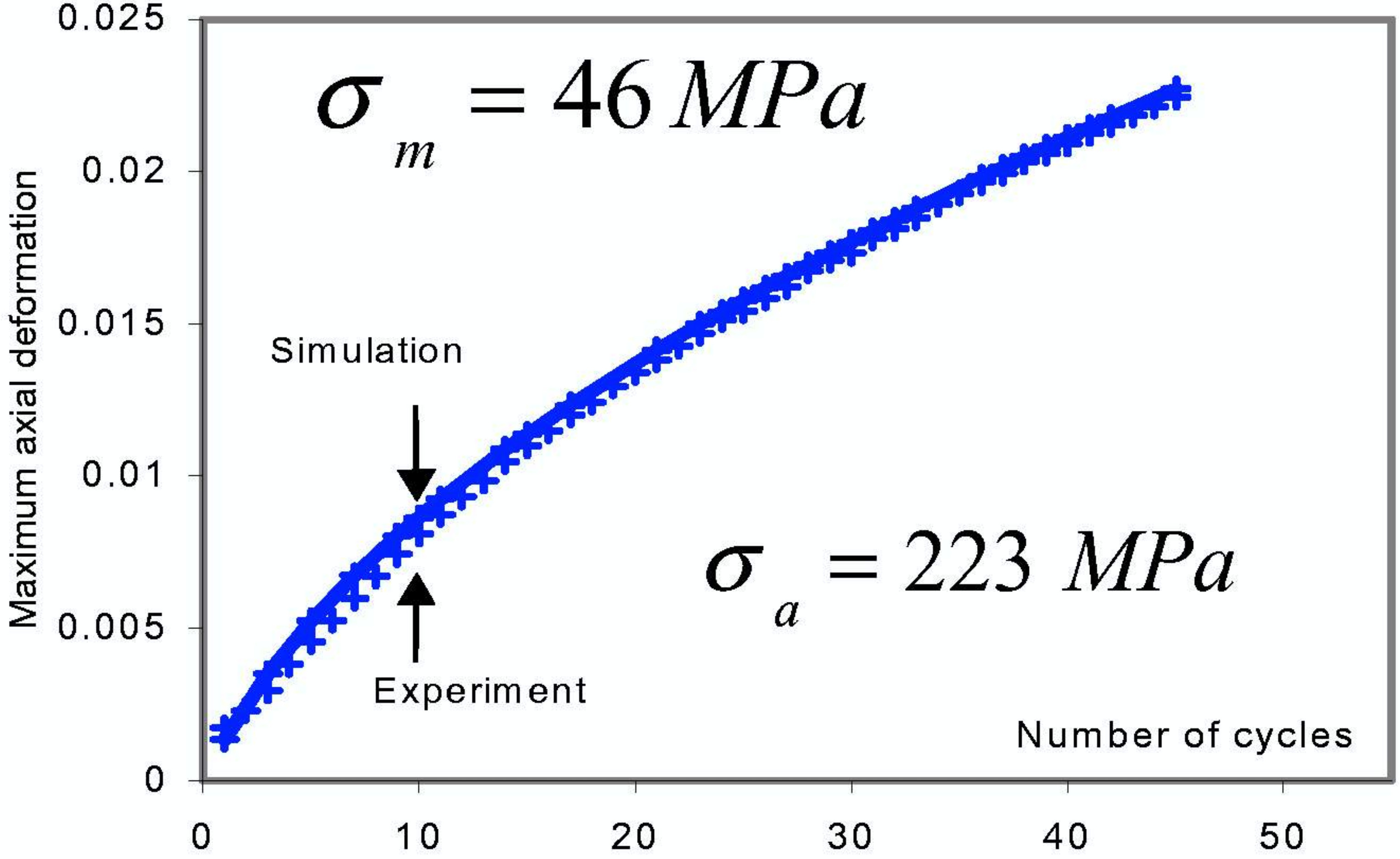
Identification of the 2M1C model on ratchetting tests by Hassan et al



Cooperation with Lakhdar Taleb (INSA Rouen, France)

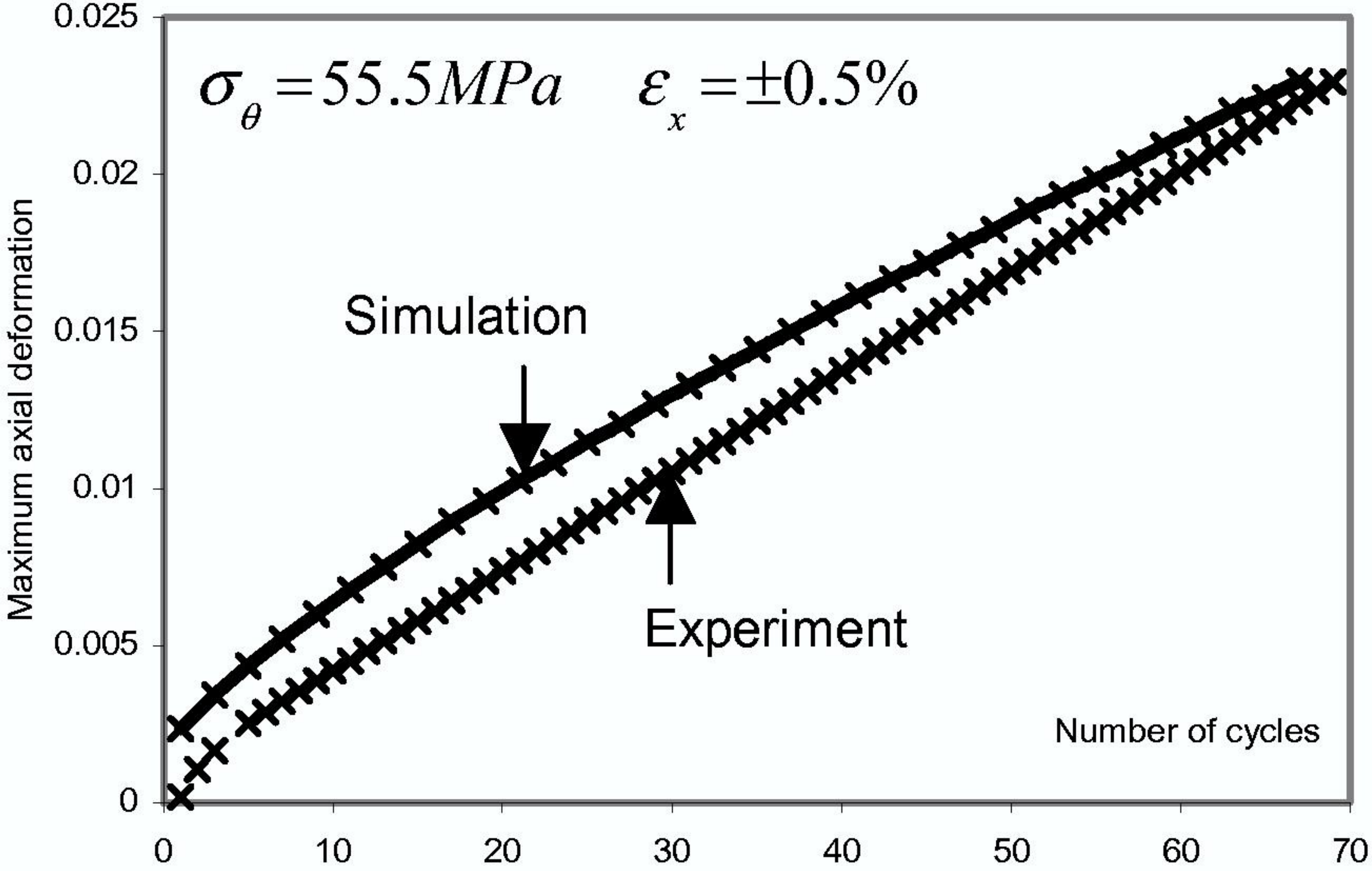
The following transparencies were prepared by L. Taleb for Plasticity'2003

Identification of the 2M1C model on ratchetting tests: 1D test



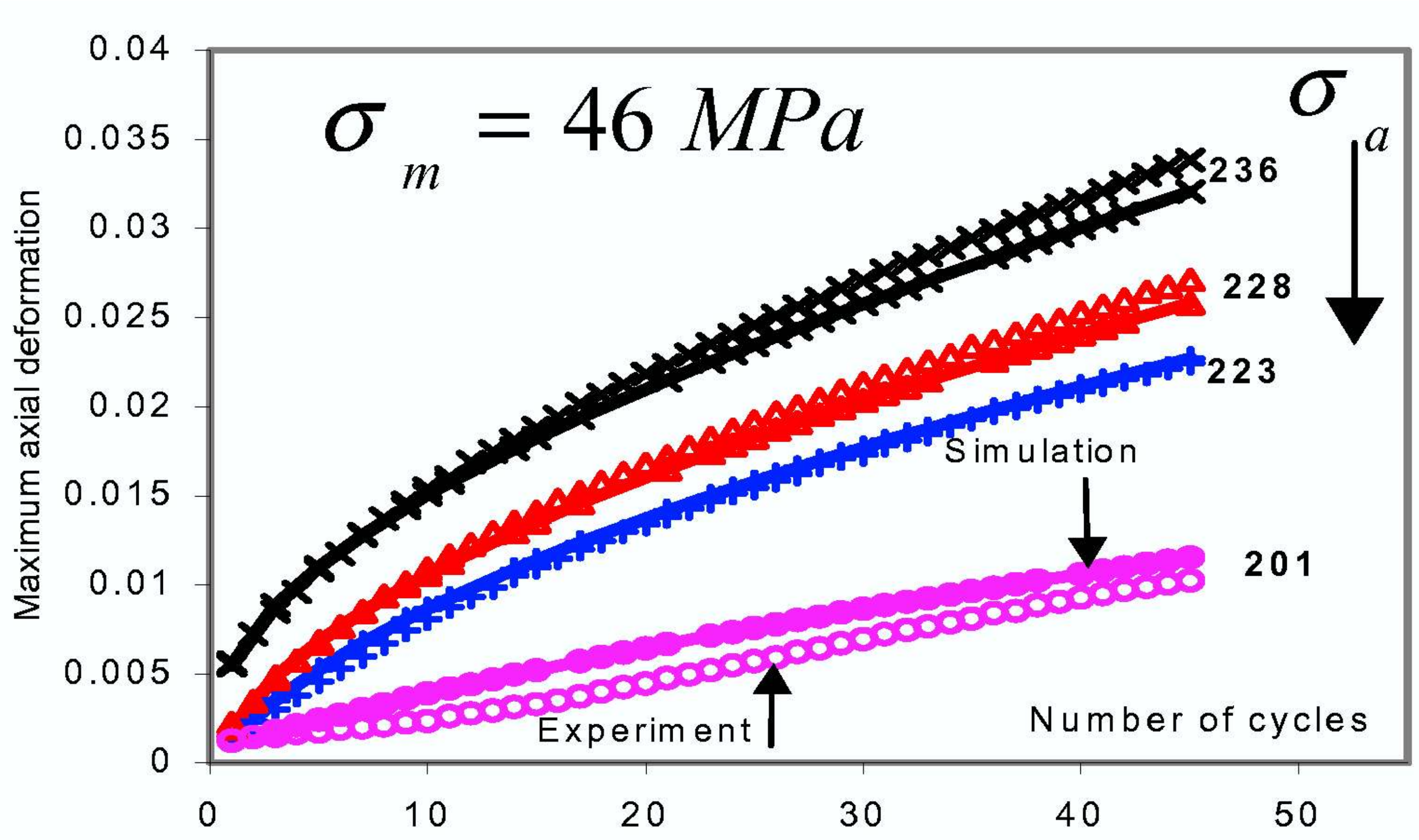
Unsymmetrical onedimensional loading – Coop. Taleb

Identification of the 2M1C model on ratchetting tests: 2D test



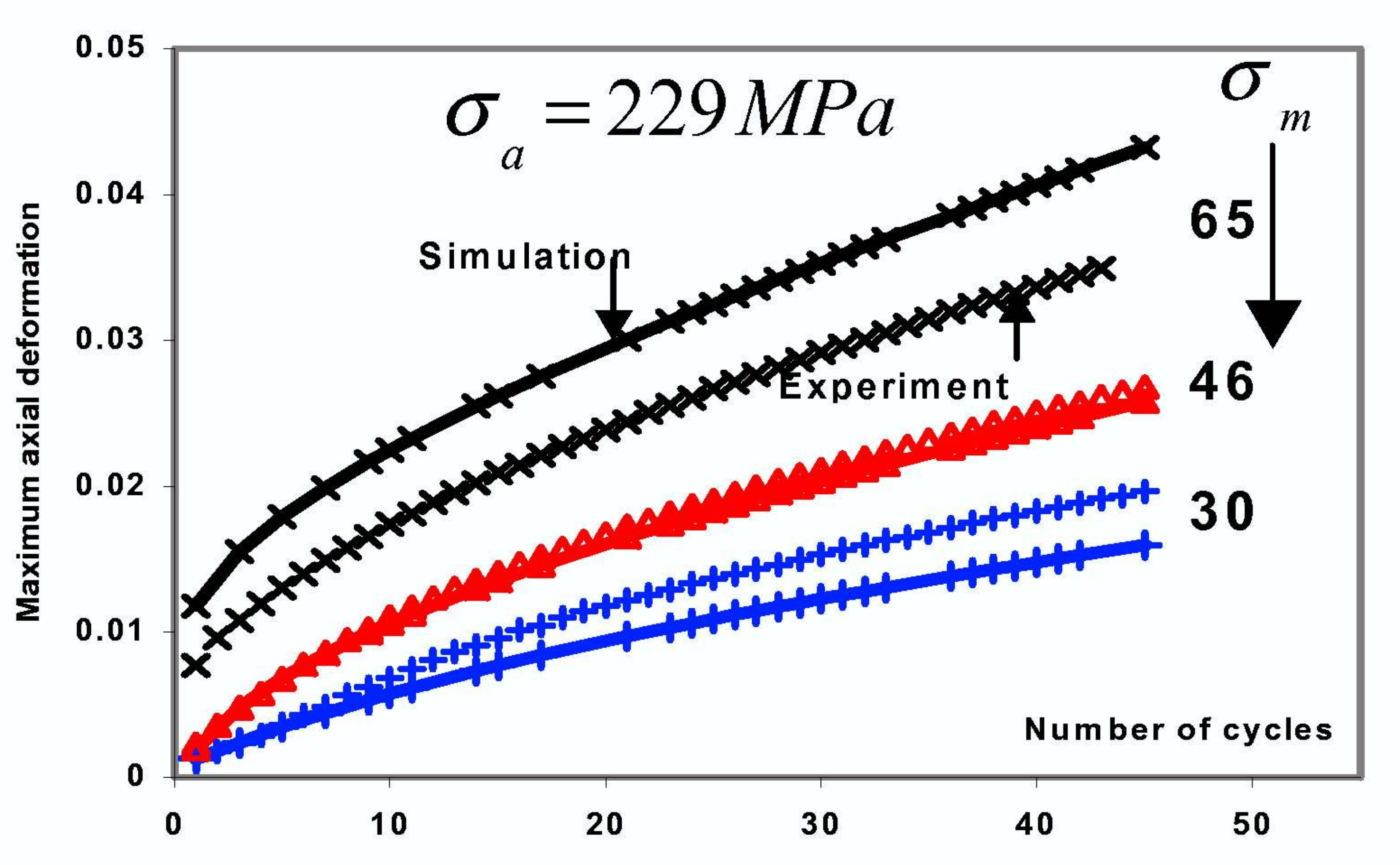
Alternate axial strain and constant hoop stress – Coop. Taleb

2M1C model: summary of 1D tests with varying stress amplitude



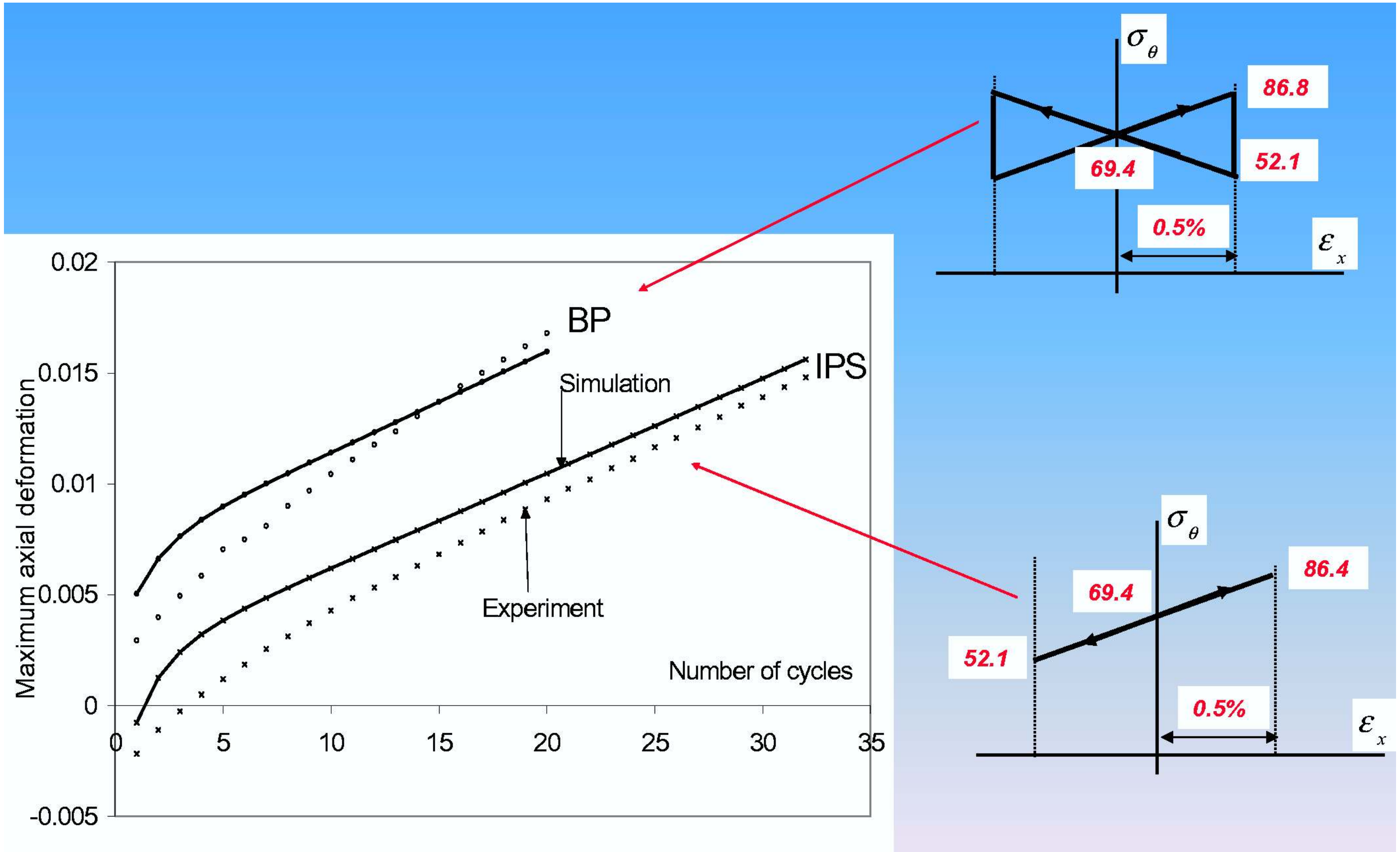
Coop. Taleb

2M1C model: summary of 1D tests with varying mean stress



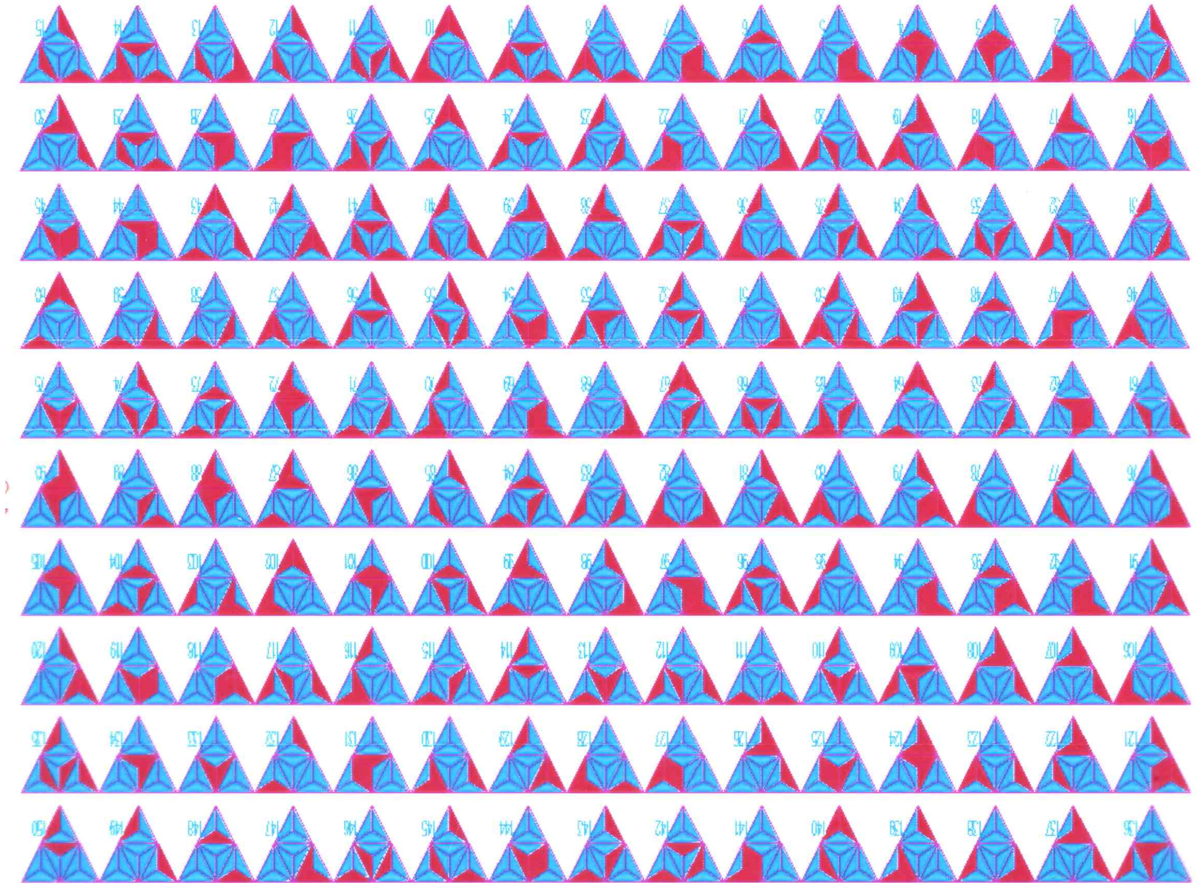
Coop. Taleb

2M1C model: Complex loading paths in 2D loading



Coop. Taleb

Identification of the polycrystal model on tests by Hassan **et al**



1000 grains are used in the polycrystal model

View of the active slip systems for a 2D test with constant hoop stress (75 MPa)

and symmetric axial loading under strain control ($\pm 0.5\%$)

Rules for the ratchetting in the polycrystal model

- Two-level kinematic hardening (*inside* the grain and at the *intergranular* level (the β–rule))
- To suppress ratchetting, you must suppress it at both levels:
  - ⋆ Introduce a linear term in intragranular hardening for the single crystal:

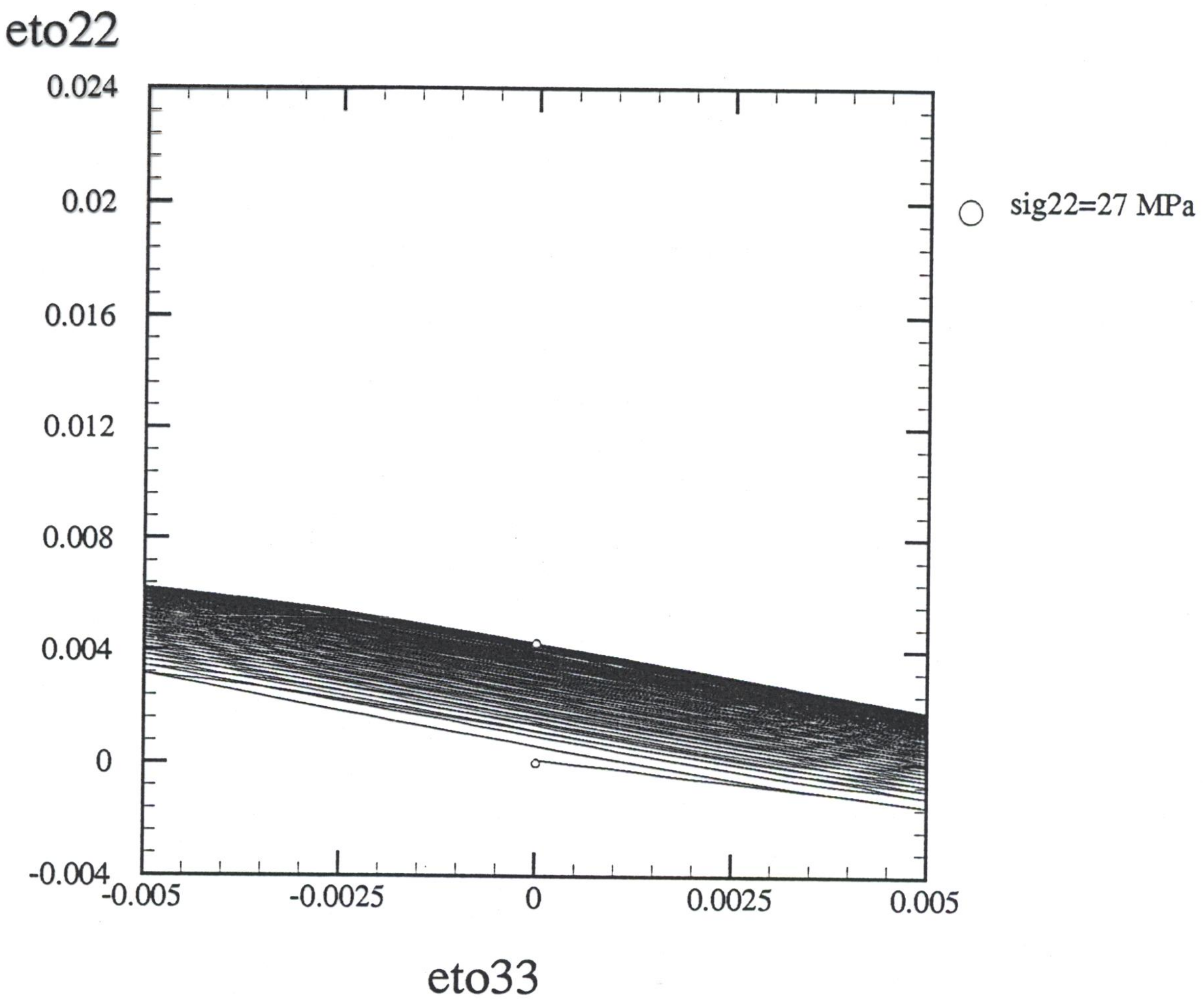
$$x^s = C\gamma^s$$

  - ⋆ Introduce a linear term in $\underset{\sim}{\boldsymbol{\beta}}$ (new coefficient δ:

$$\dot{\underset{\sim}{\boldsymbol{\beta}}} = \dot{\underset{\sim}{\boldsymbol{\varepsilon}}}^g - D(\underset{\sim}{\boldsymbol{\beta}} - \delta\underset{\sim}{\boldsymbol{\varepsilon}}^g)||\dot{\underset{\sim}{\boldsymbol{\varepsilon}}}^g||$$

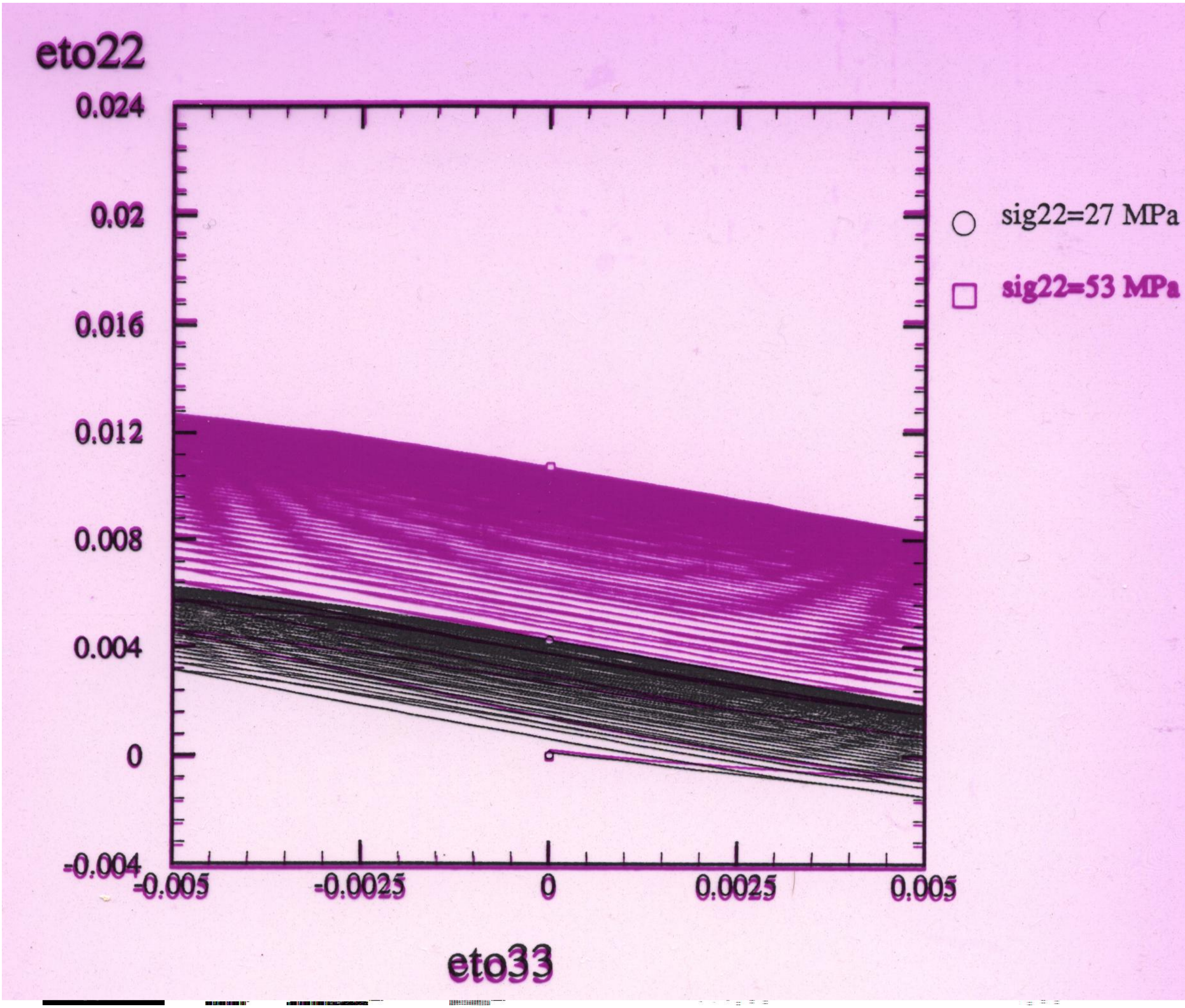
- Note that 2D ratchetting is also related to the *shape* and the *distorsion* of the yield surface (additional capabilities for the polycrystal model)

Simulation of Hassan's 2D test with the polycrystal model (1)



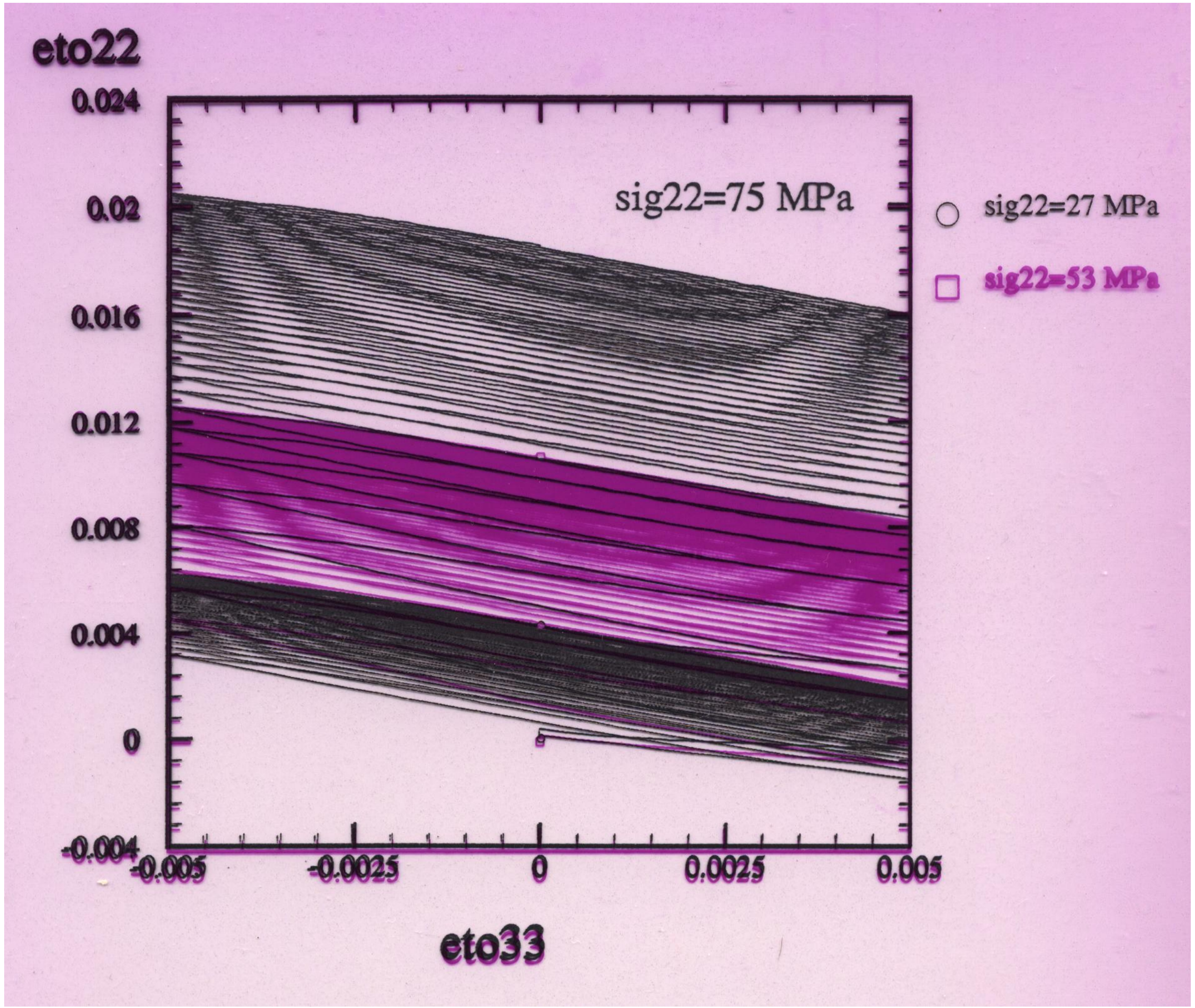
Axial loading $\pm 0.5\%$, *hoop stress 27 MPa*

Simulation of Hassan's 2D test with the polycrystal model (2)



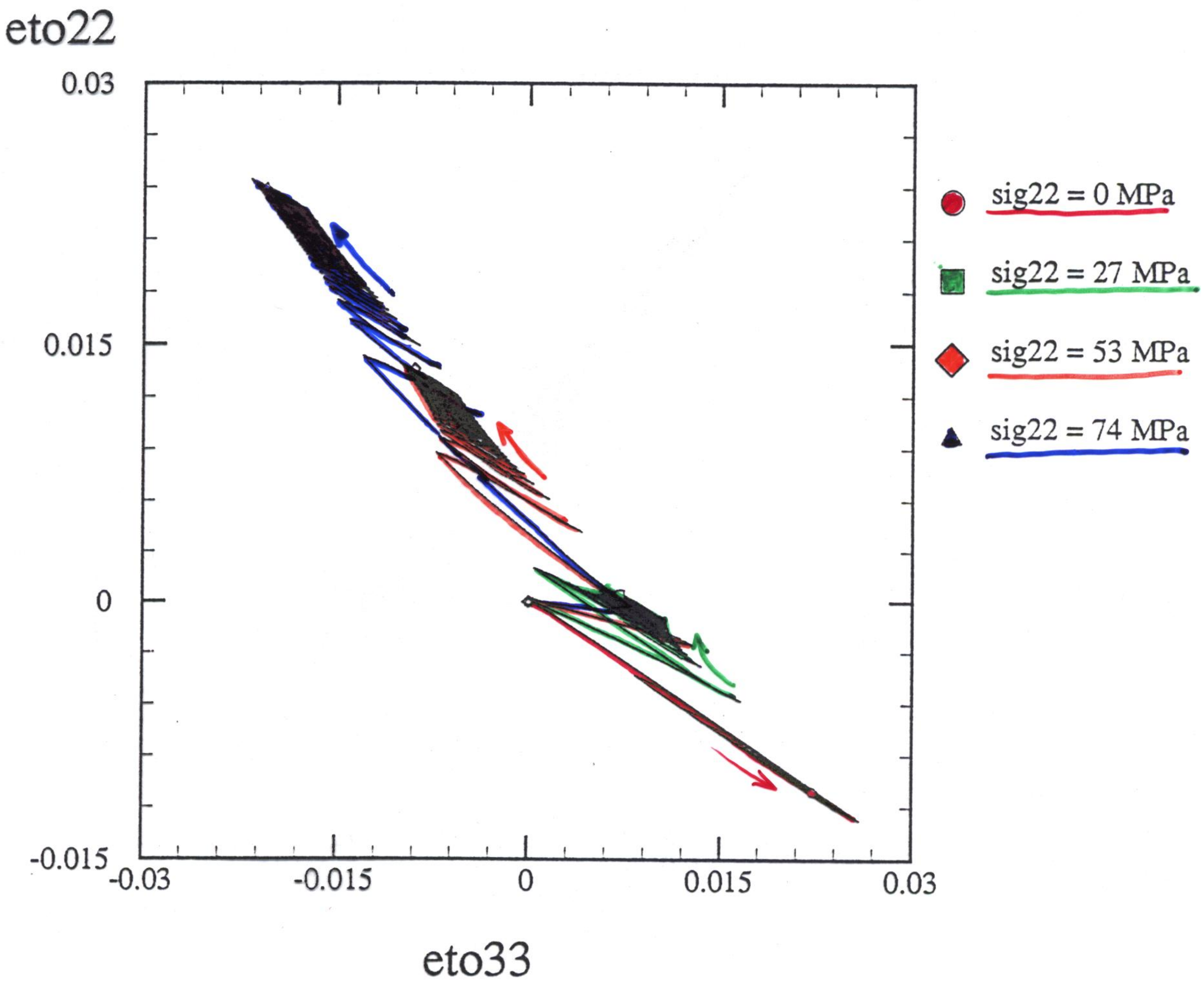
Axial loading $\pm 0.5\%$, hoop stress 27, 53 MPa

Simulation of Hassan's 2D test with the polycrystal model (3)



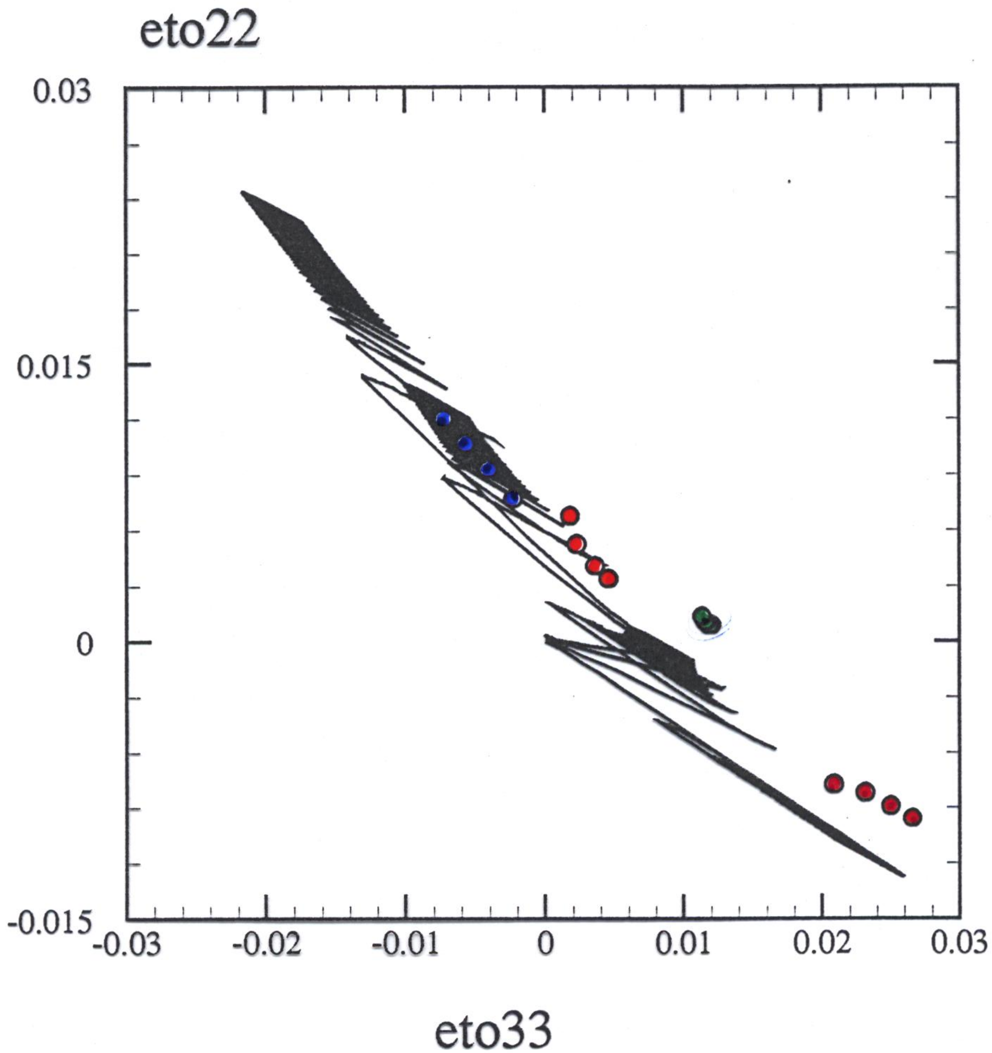
Axial loading $\pm 0.5\%$, hoop stress 27, 53, 75 MPa

Response in the axial strain–hoop strain plane for cst hoop stress and alt axial strain



Simulation with the polycrystal model

Response in the axial strain–hoop strain plane for cst hoop stress and alt axial strain



Comparison with experiment

Ratchetting

- **Caution, the classical (isotropic, linear kinematic) models suppress ratchetting (non conservative approaches)**
- **Several responses, at various scales**
- **The relation microstructure-property is still unclear**

–Still an open problem–