Experimental identification of thermo-mechanical cohesive zone models for complex loading

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Motivation

Methodology:
Inverse method

Objectives:
Identification of cohesive zone models for heterogeneous materials

Measurements:
Thermomechanical imaging techniques

Methodology

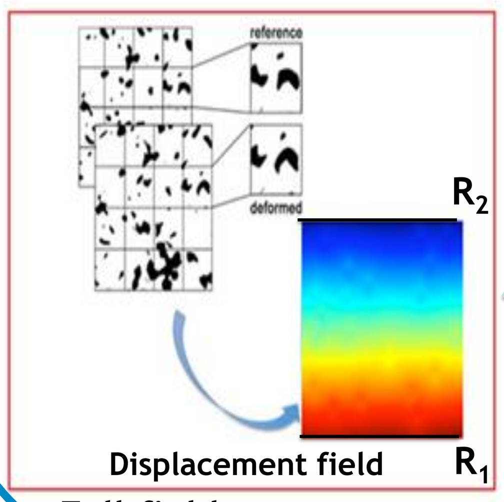
Step 1: identify the stress field from the strain field.

Finite element analysis

Determine the mechanical properties of a material by minimizing the energy difference between the "measured" (U_m) and a "computed" (U_c) displacement fields.

$\{U_m, \vec{R}_i\}$

$$E(U_c, B(p)) = \frac{1}{2T}\int_0^t \int_\Omega \left(B(p):\varepsilon[U_c] - B(p):\varepsilon[U_m]\right):B(p)^{-1}:\left(B(p):\varepsilon[U_c] - B(p):\varepsilon[U_m]\right) dV\,dt$$



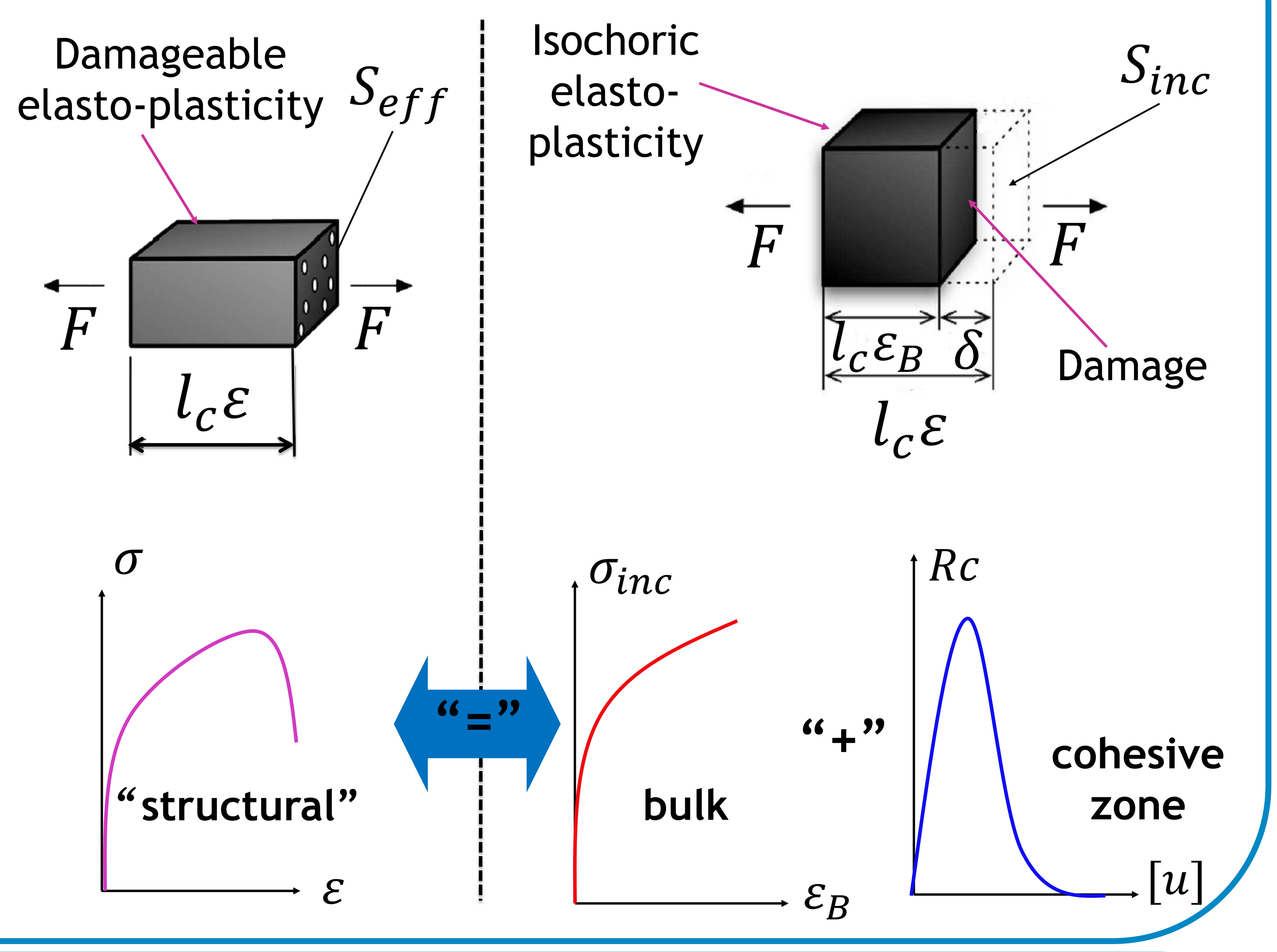
Full-field measurements

$\{U_m, \vec{R}_i\}$

$$\min E(U_c, B(p))$$

$U_c \to \varepsilon_c \to \sigma_c$
and
$p = \{E, v, G, \sigma_0, k\}$

Step 2: summarize the « volume » damage as a « surface » damage.



Constitutive Equation Gap Method (CEGM)

Elastic identification

- $B(p)$ independent of loading, Explicit estimate of the elastic parameters (cubic):

$$\frac{1}{E^{(i)}} = \frac{1}{2}\left(\sqrt{\frac{\int_t \int_{w_i}\left(\varepsilon^m{}_{xx} - \varepsilon^m{}_{yy}\right)^2 dV\,dt}{\int_t \int_{w_i}\left(\sigma^c{}_{xx} - \sigma^c{}_{yy}\right)^2 dV\,dt}} + \sqrt{\frac{\int_t \int_{w_i}\left(\varepsilon^m{}_{xx} + \varepsilon^m{}_{yy}\right)^2 dV\,dt}{\int_t \int_{w_i}\left(\sigma^c{}_{xx} + \sigma^c{}_{yy}\right)^2 dV\,dt}}\right)$$

$$v^{(i)} = \frac{E^{(i)}}{2}\left(\sqrt{\frac{\int_t \int_{w_i}\left(\varepsilon^m{}_{xx} - \varepsilon^m{}_{yy}\right)^2 dV\,dt}{\int_t \int_{w_i}\left(\sigma^c{}_{xx} - \sigma^c{}_{yy}\right)^2 dV\,dt}} - \sqrt{\frac{\int_t \int_{w_i}\left(\varepsilon^m{}_{xx} + \varepsilon^m{}_{yy}\right)^2 dV\,dt}{\int_t \int_{w_i}\left(\sigma^c{}_{xx} + \sigma^c{}_{yy}\right)^2 dV\,dt}}\right)$$

$$G^{(i)} = \frac{1}{2}\left(\sqrt{\frac{\int_t \int_{w_i}\left(\sigma^c{}_{xy}\right)^2 dV\,dt}{\int_t \int_{w_i}\left(\varepsilon^m{}_{xy}\right)^2 dV\,dt}}\right)$$

- $B(p)$ depends on the Von Mises stress σ_n^{eq}:

$$B(p) = \begin{bmatrix} \frac{E(1+2KE)}{3K^2E^2 - 2KE(v-2) + 1 - v^2} & \frac{E(v+KE)}{3K^2E^2 - 2KE(v-2) + 1 - v^2} & 0 \\ \frac{E(v+KE)}{3K^2E^2 - 2KE(v-2) + 1 - v^2} & \frac{E(1+2KE)}{3K^2E^2 - 2KE(v-2) + 1 - v^2} & 0 \\ 0 & 0 & \frac{G}{1+6KG} \end{bmatrix}$$

- Resolution of the non-linear system obtained by the stationarity condition with respect to « a » and « b »,
- Computation of K and α,
- Determination of σ_0 and k by a linear fit of the data $\sqrt{\frac{3}{2}}\alpha = f(2\sqrt{\frac{3}{2}}K\alpha)$ $\Rightarrow$ k is the slope of the curve and σ_0 is the intersection of the curve with the y axis.

Plastic identification

$$\alpha^2 = (\sigma - X)^T P(\sigma - X)$$

$$\Delta\gamma = \frac{3}{2k}\left(\sqrt{\frac{3}{2}}\frac{\alpha}{\sigma_0} - 1\right)$$

$$K = \frac{\Delta\gamma}{3 + 2 * \Delta\gamma}$$

Rewrite K

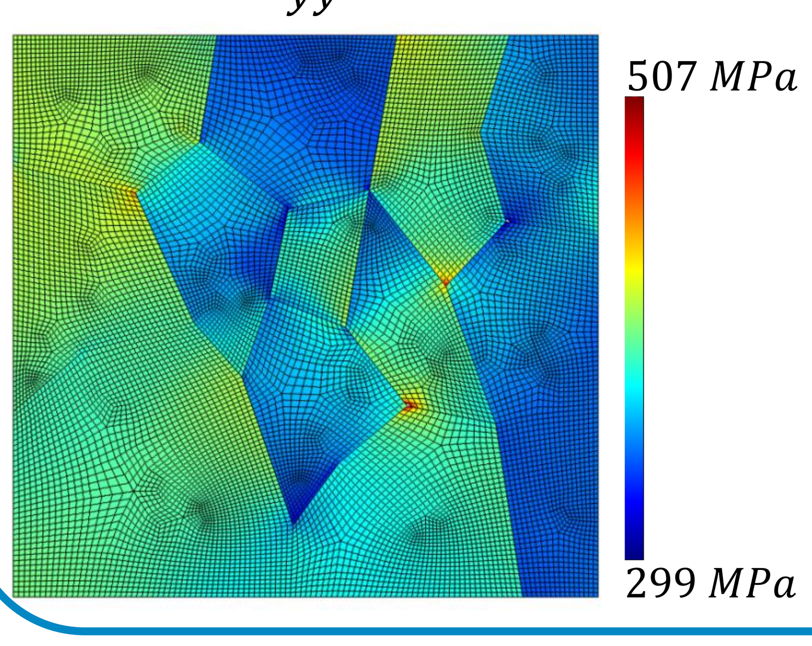
$$K = a\frac{\|\Delta\varepsilon^p\|}{b + \|\Delta\varepsilon^p\|}$$

$$\text{with } a = \frac{1}{2k} \text{ and } b = \frac{\sigma_0}{k}$$

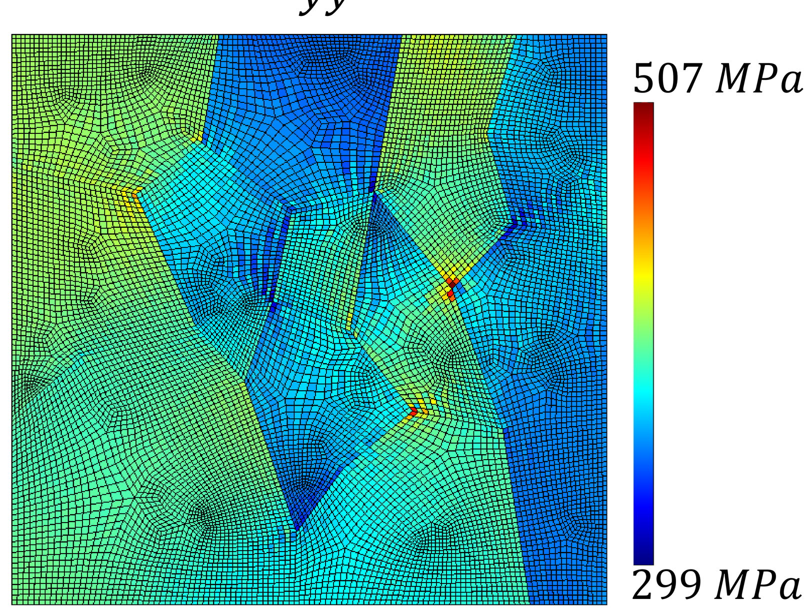
Results: Polycrystalline structure

Distribution of transversal stress fields, mesh perfectly consistent with the material heterogeneity:

σ_{yy}^m

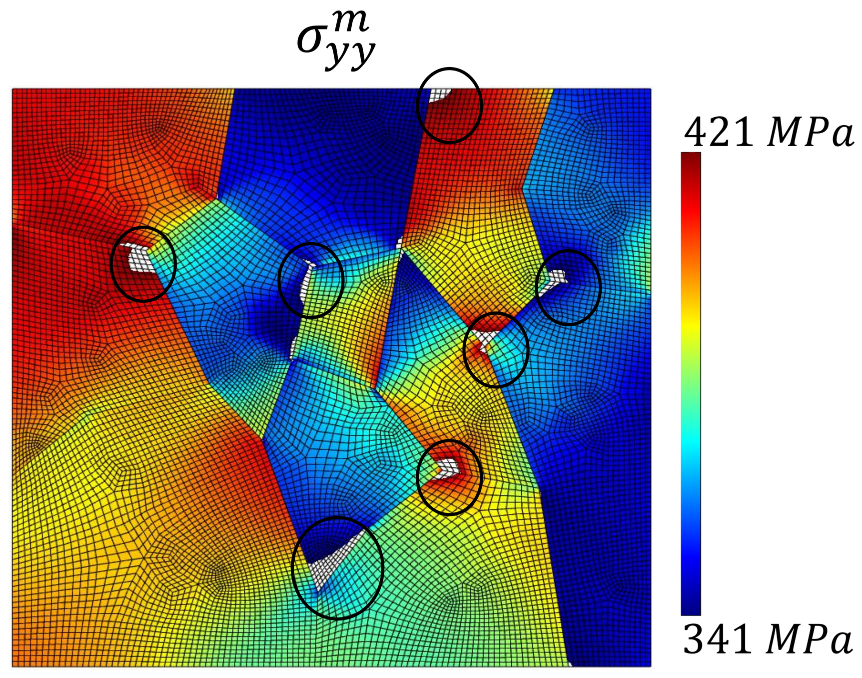


σ_{yy}^c

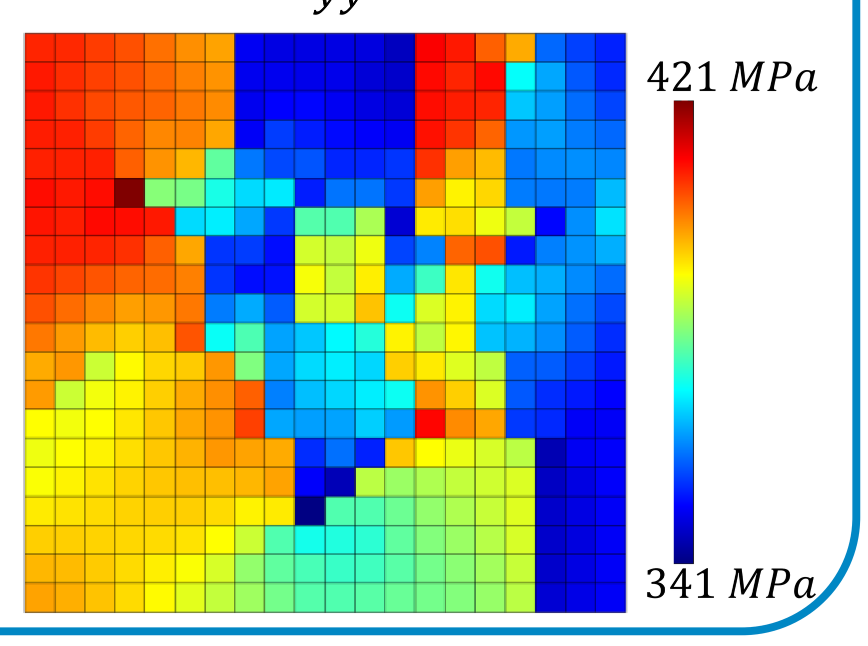


Distribution of transversal stress fields, mesh doesn't match the material heterogeneity:

σ_{yy}^m



σ_{yy}^c



Conclusions :

- Identification of heterogeneous fields (stress, …) for elasto-plastic behavior: linear and non-linear hardening.
- Application of this method to real full-field measurements.

Prospect :

- Extend the constitutive equation gap method to softening behaviors.
- Identification of Cohesive Zone Models.
- Introduction of a calorimetric gap in the identification functional.