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

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Methodology:
Inverse method

Motivation

Measurements:
Thermomechanical imaging techniques

Objectives:

Identification of cohesive zone models for heterogeneous materials

Methodology

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

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



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.

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

$$E(U_c, B(p)) =$$

$$\frac{1}{2T} \int_0^t \int_{\Omega} (B(p) : \epsilon[U_c] - B(p) : \epsilon[U_m]) : B(p)^{-1} : (B(p) : \epsilon[U_c] - B(p) : \epsilon[U_m]) dV dt$$

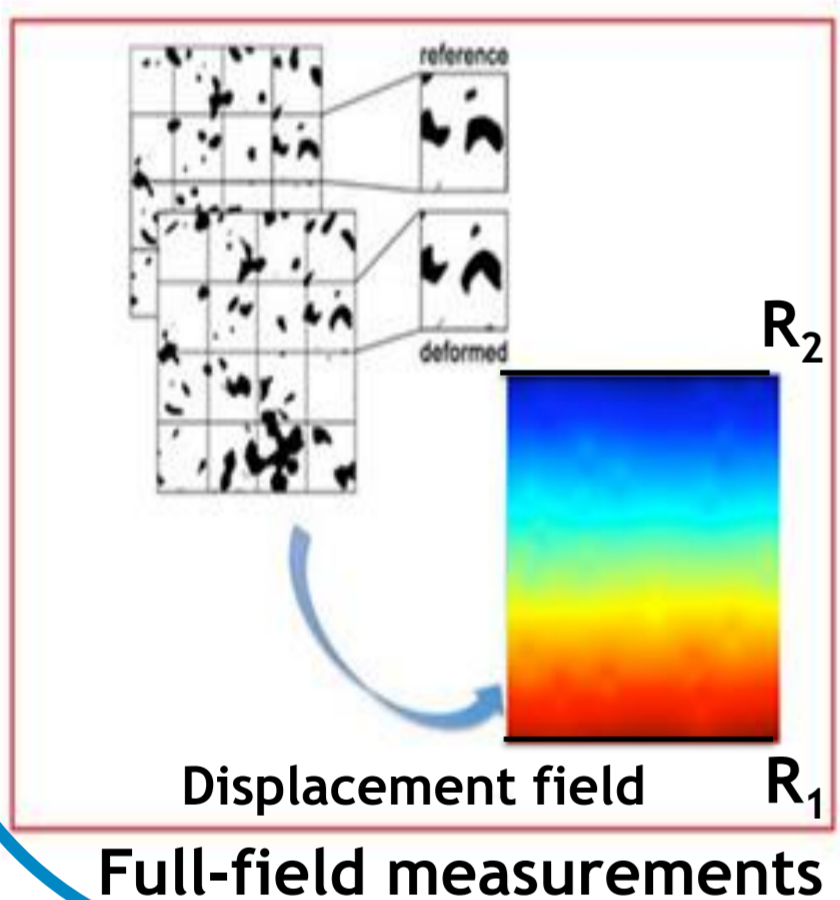
$\{U_m, \vec{R}_i\}$

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

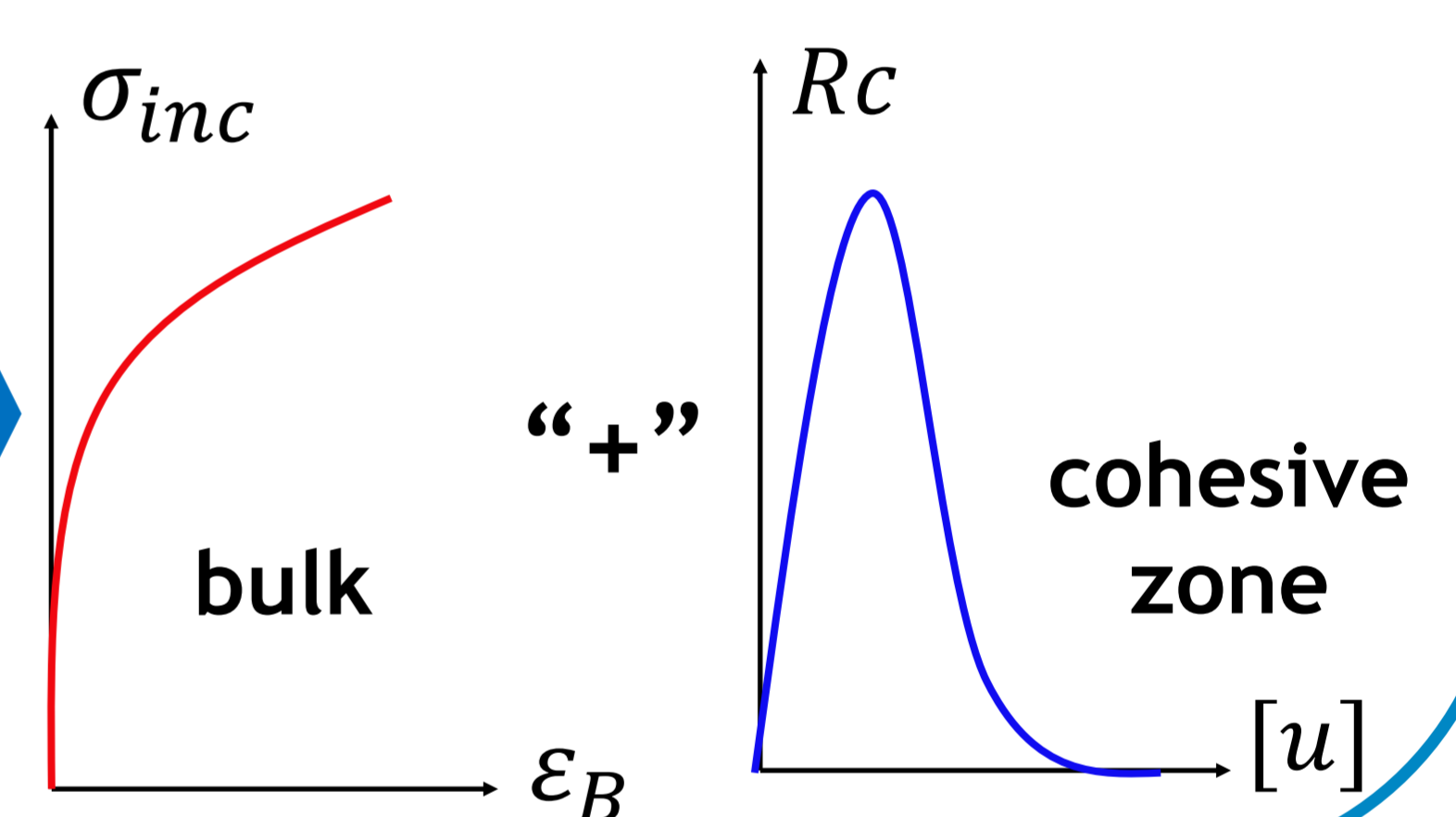
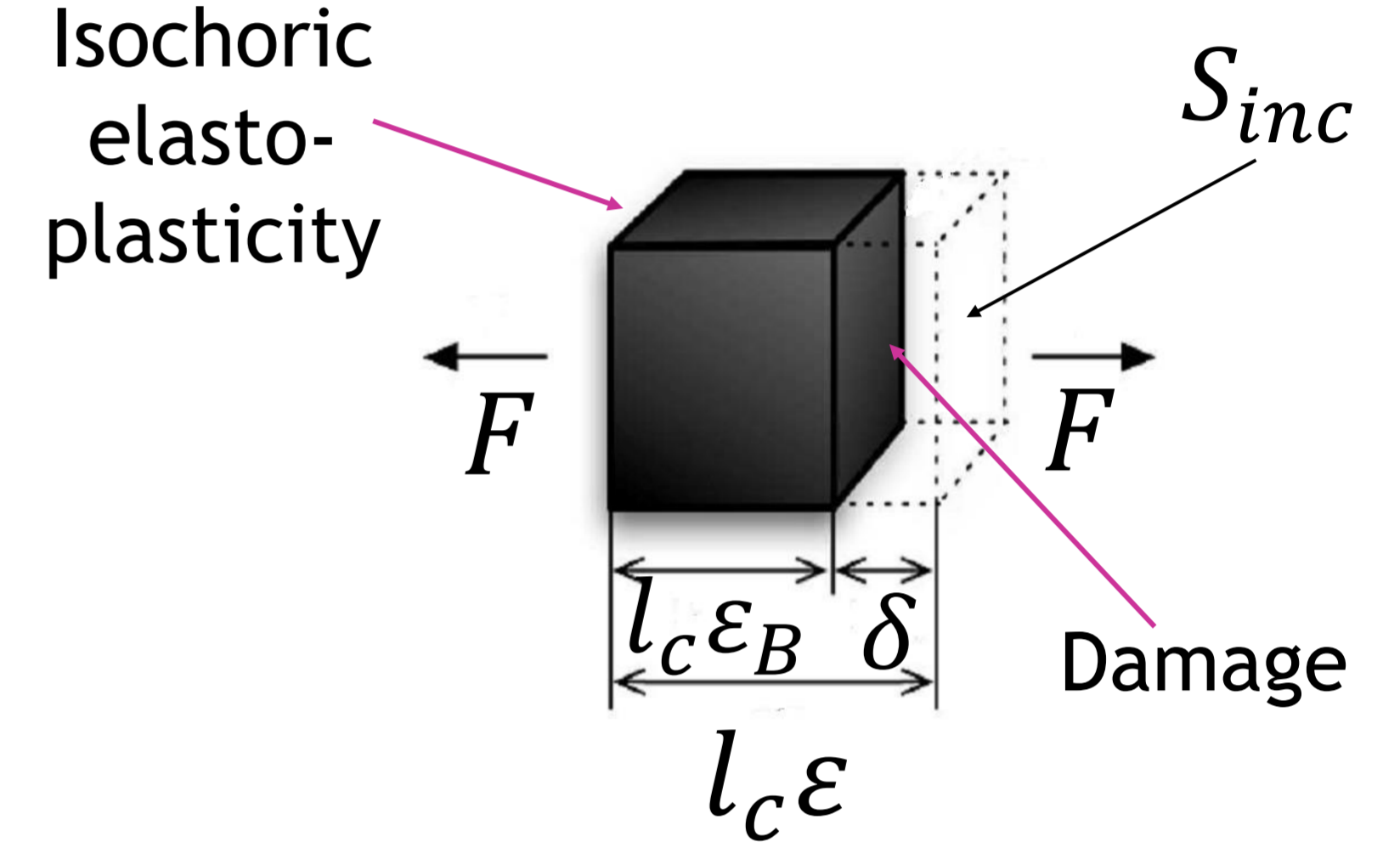
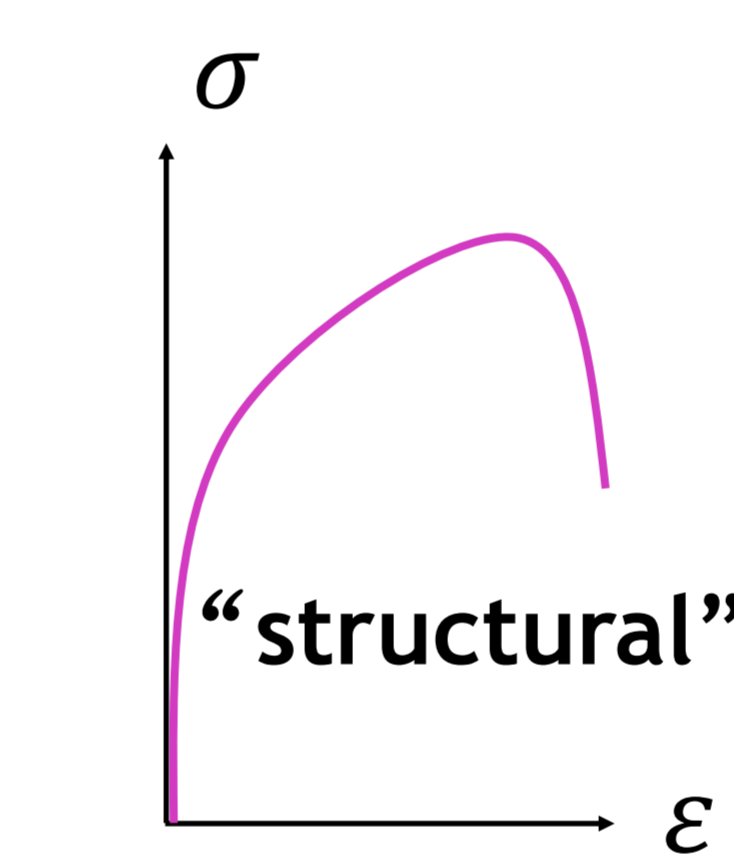
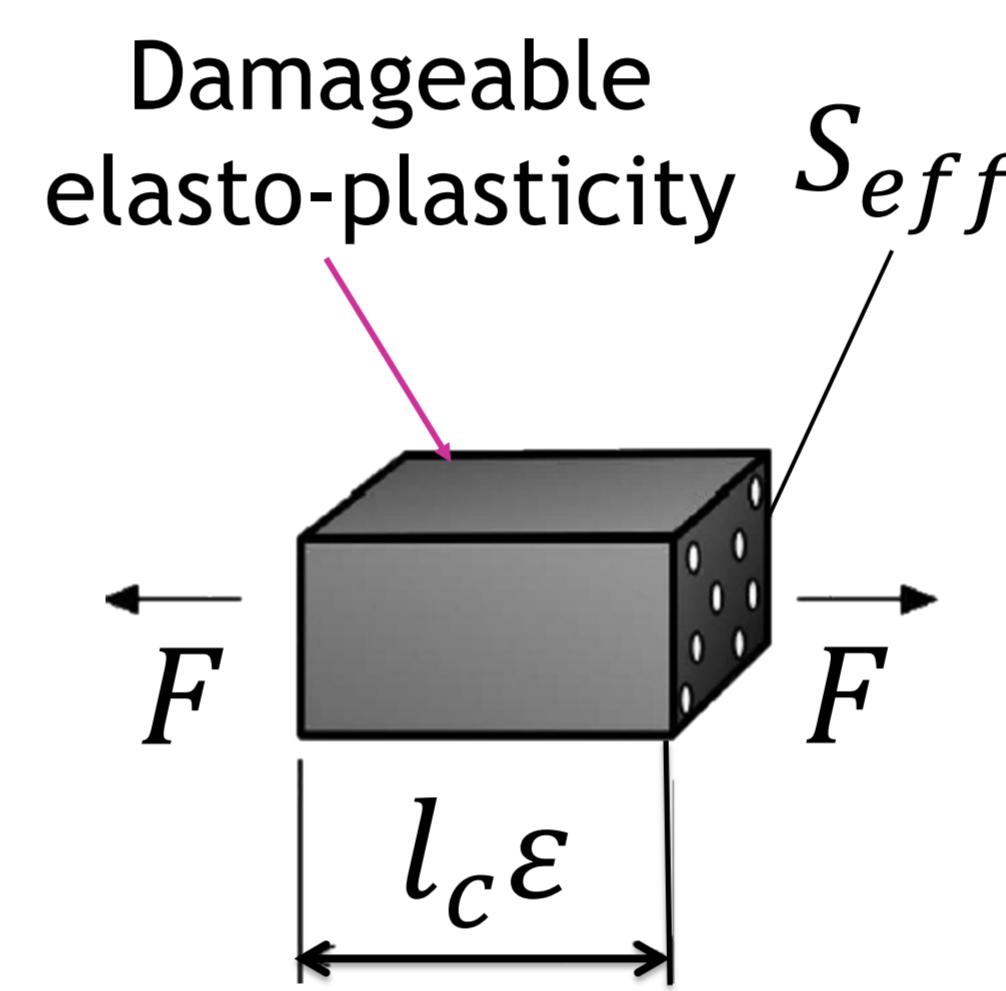
$$U_c \rightarrow \epsilon_c \rightarrow \sigma_c$$

and

$$p = \{E, \nu, G, \sigma_0, k\}$$



Displacement field R_1
Full-field measurements



Elastic identification

Constitutive Equation Gap Method (CEGM)

Plastic identification

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

$$\frac{1}{E^{(i)}} = \frac{1}{2} \left(\frac{\int_t \int_{w_i} (\epsilon_{xx}^m - \epsilon_{yy}^m)^2 dV dt}{\int_t \int_{w_i} (\sigma_{xx}^c - \sigma_{yy}^c)^2 dV dt} + \frac{\int_t \int_{w_i} (\epsilon_{xx}^m + \epsilon_{yy}^m)^2 dV dt}{\int_t \int_{w_i} (\sigma_{xx}^c + \sigma_{yy}^c)^2 dV dt} \right)$$

$$\nu^{(i)} = \frac{E^{(i)}}{2} \left(\frac{\int_t \int_{w_i} (\epsilon_{xx}^m - \epsilon_{yy}^m)^2 dV dt}{\int_t \int_{w_i} (\sigma_{xx}^c - \sigma_{yy}^c)^2 dV dt} - \frac{\int_t \int_{w_i} (\epsilon_{xx}^m + \epsilon_{yy}^m)^2 dV dt}{\int_t \int_{w_i} (\sigma_{xx}^c + \sigma_{yy}^c)^2 dV dt} \right)$$

$$G^{(i)} = \frac{1}{2} \left(\frac{\int_t \int_{w_i} (\sigma_{xy}^c)^2 dV dt}{\int_t \int_{w_i} (\epsilon_{xy}^m)^2 dV dt} \right)$$

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

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

- 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.

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

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

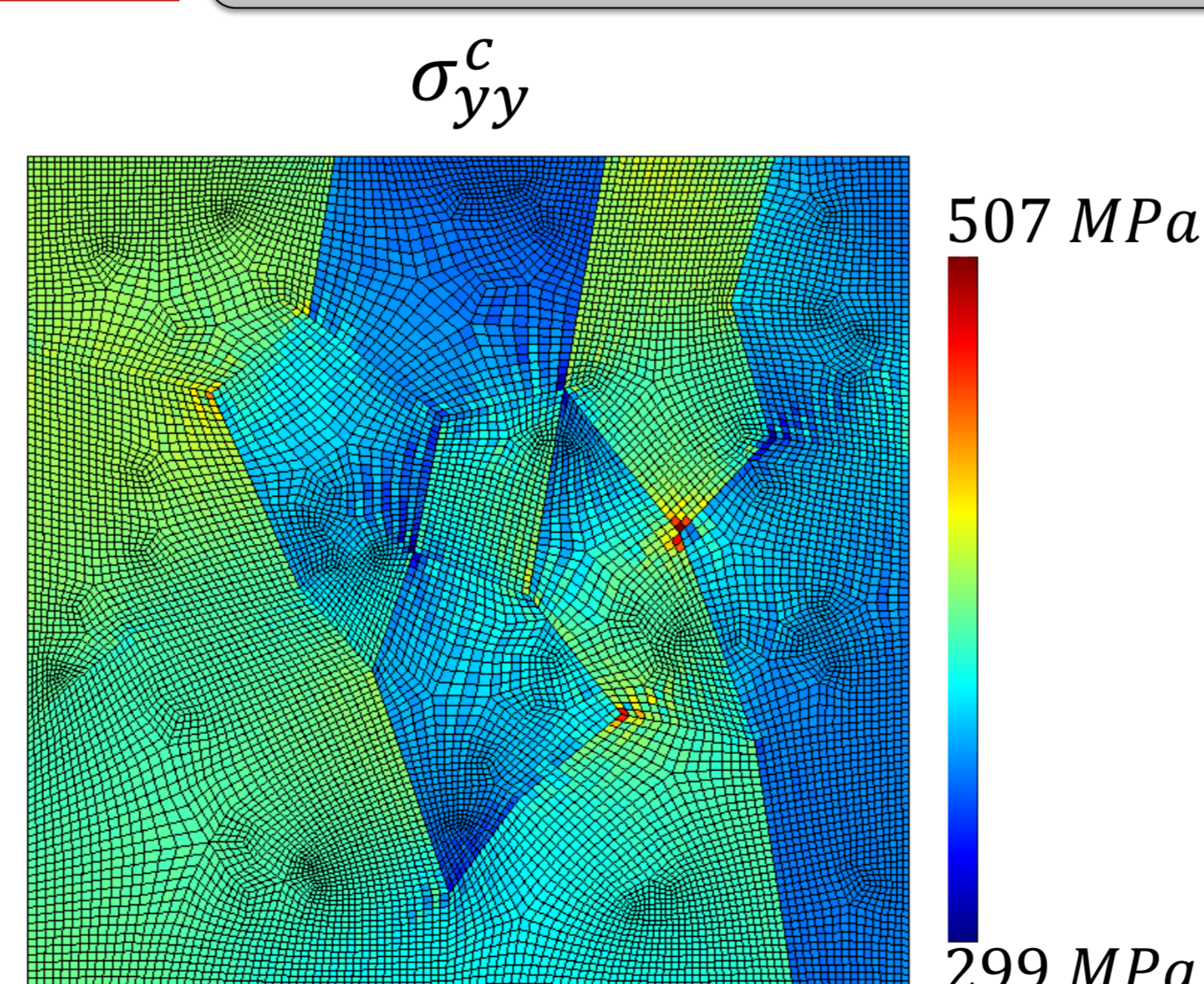
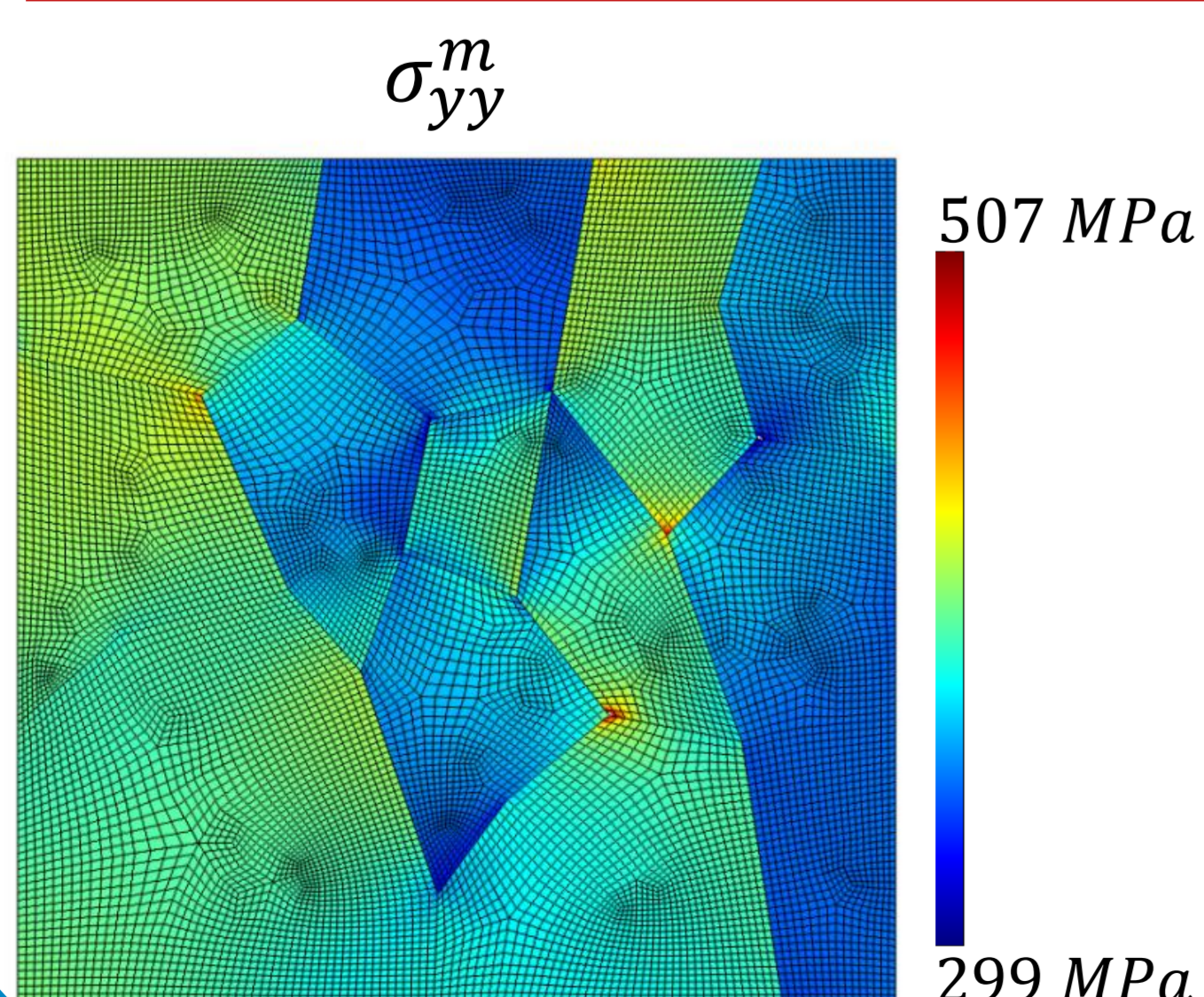
$$K = \frac{\Delta \gamma}{3 + 2 * \Delta \gamma}$$

Rewrite K

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

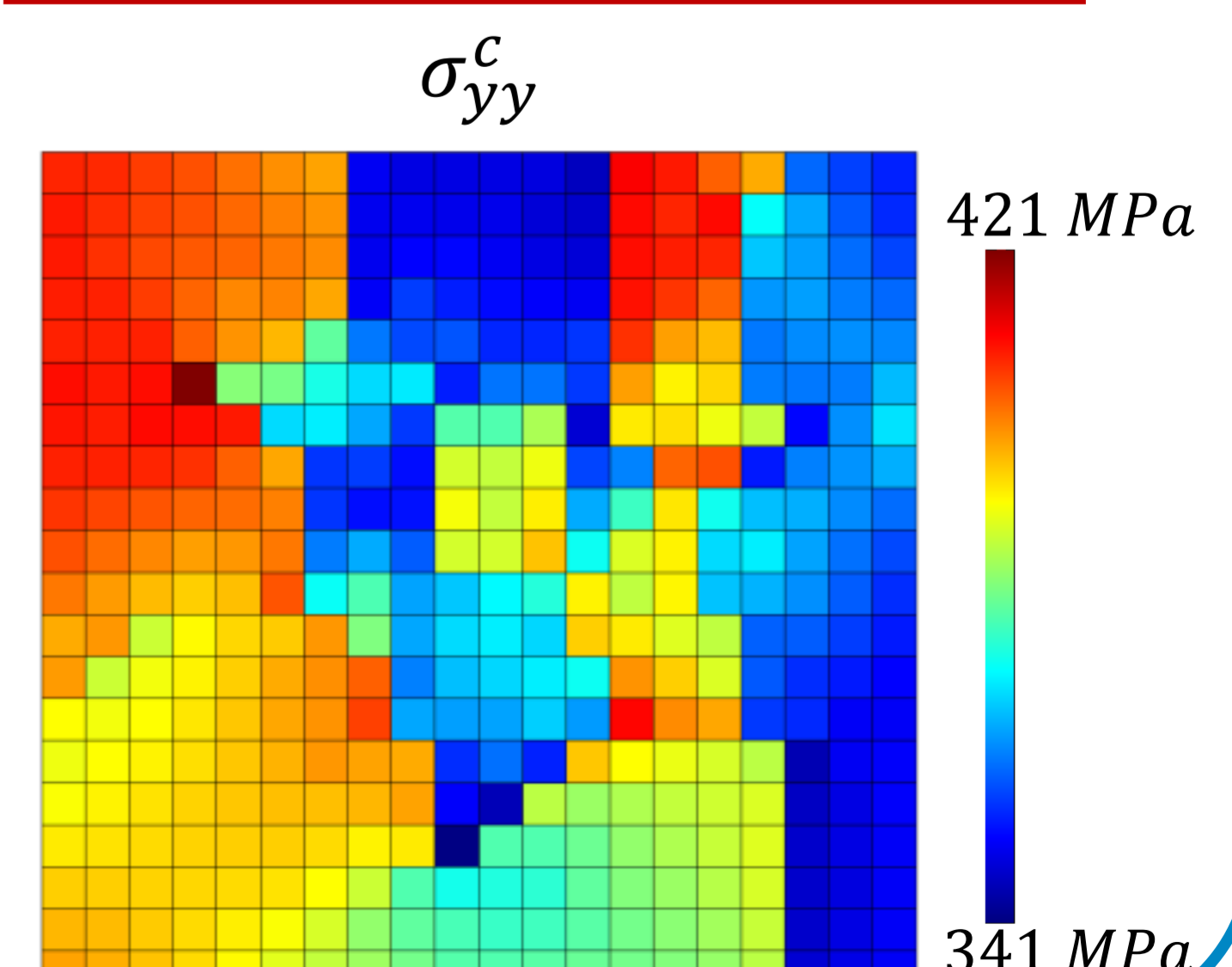
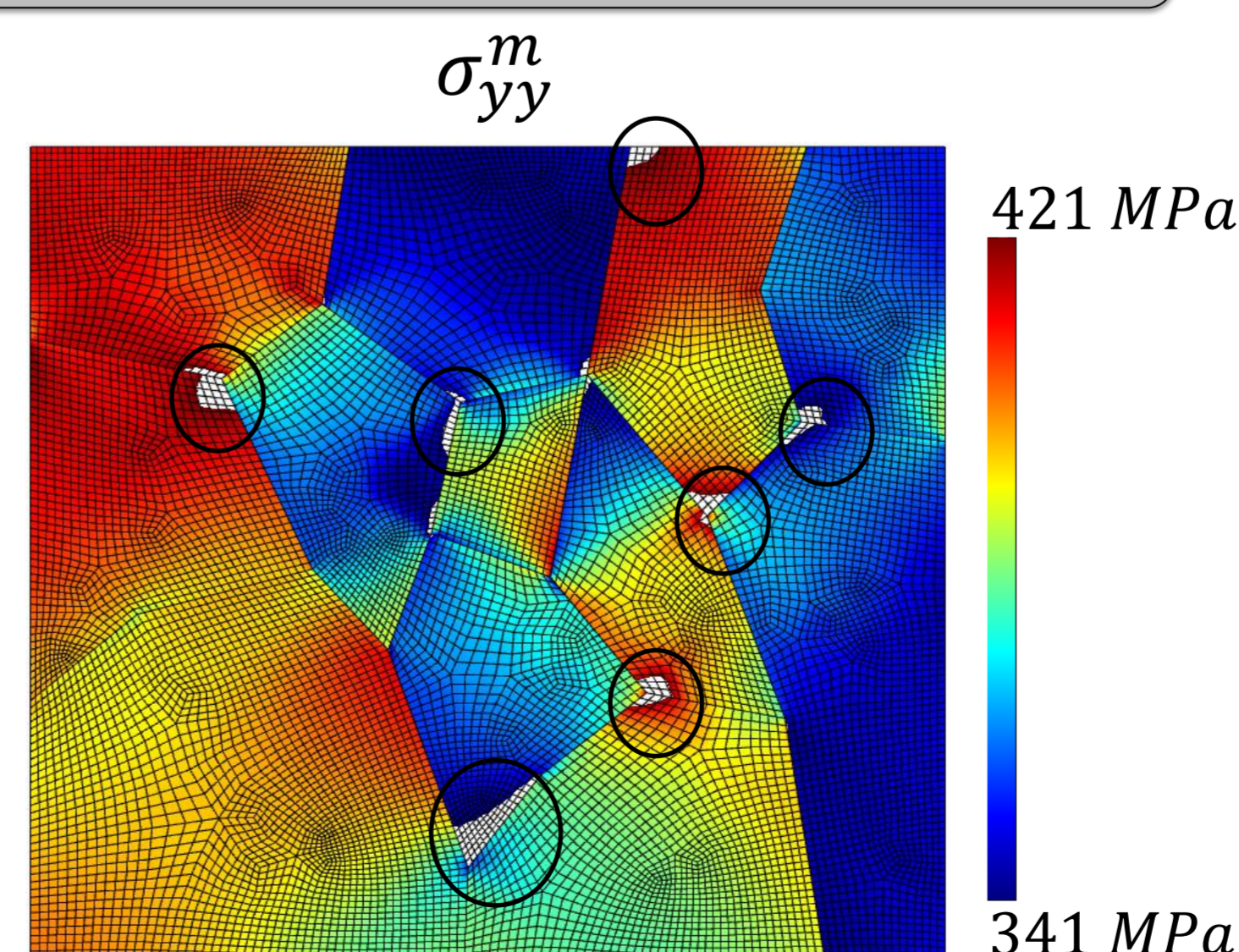
with $a = \frac{1}{2k}$ and $b = \frac{\sigma_0}{k}$

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



Results: Polycrystalline structure

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



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.