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

T.MADANI^{1,2} Y. MONERIE^{2,3} S. PAGANO^{2,3} C. PELISSOU^{1,2} B. WATTRISSE^{2,3}

¹ Institut de Radioprotection et de Sûreté Nucléaire, B.P. 3, 13115 Saint-Paul-lez-Durance Cedex, France

² Laboratoire de Micromécanique et Intégrité des Structures, IRSN-CNRS-Université de Montpellier, France

³ Laboratoire de Mécanique et Génie Civil, Université de Montpellier, CC 048, 34095 Montpellier Cedex, France

Methodology:
Inverse method

Motivation

Objectives:

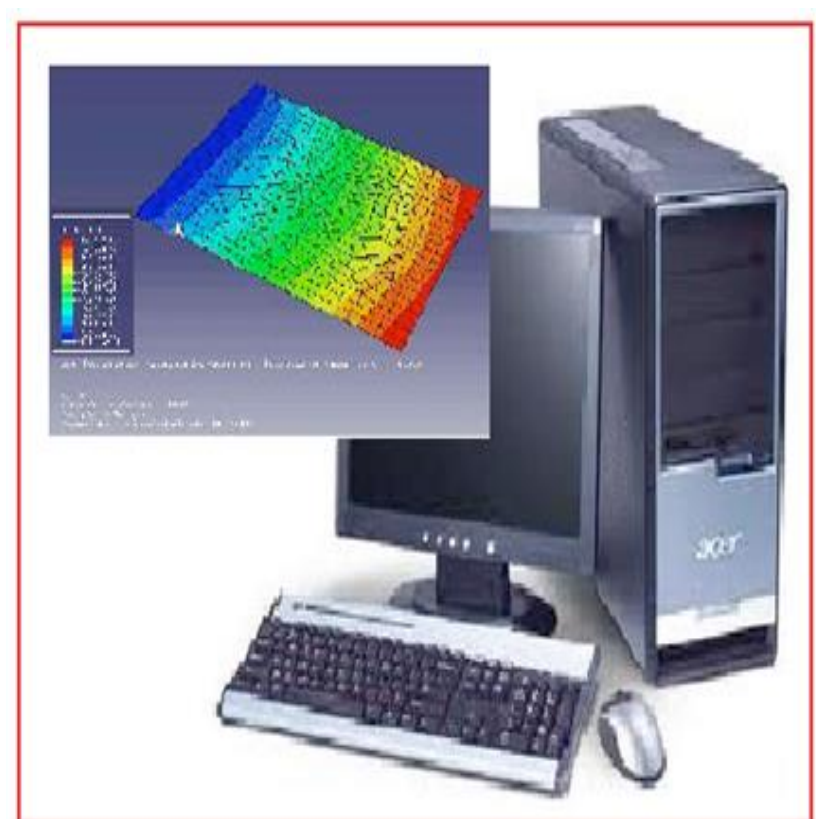
Identification of cohesive zone models for heterogeneous materials

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.

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

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

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

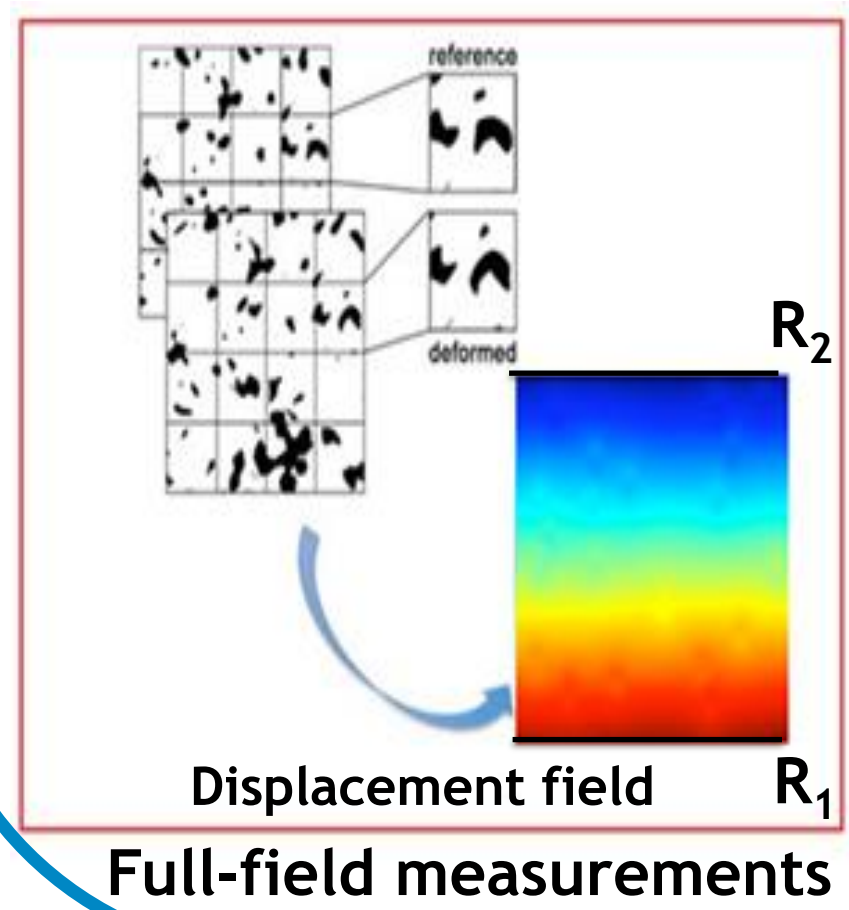
$\{U_m, \vec{R}_i\}$

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

$$U_c \rightarrow \varepsilon_c \rightarrow \sigma_c$$

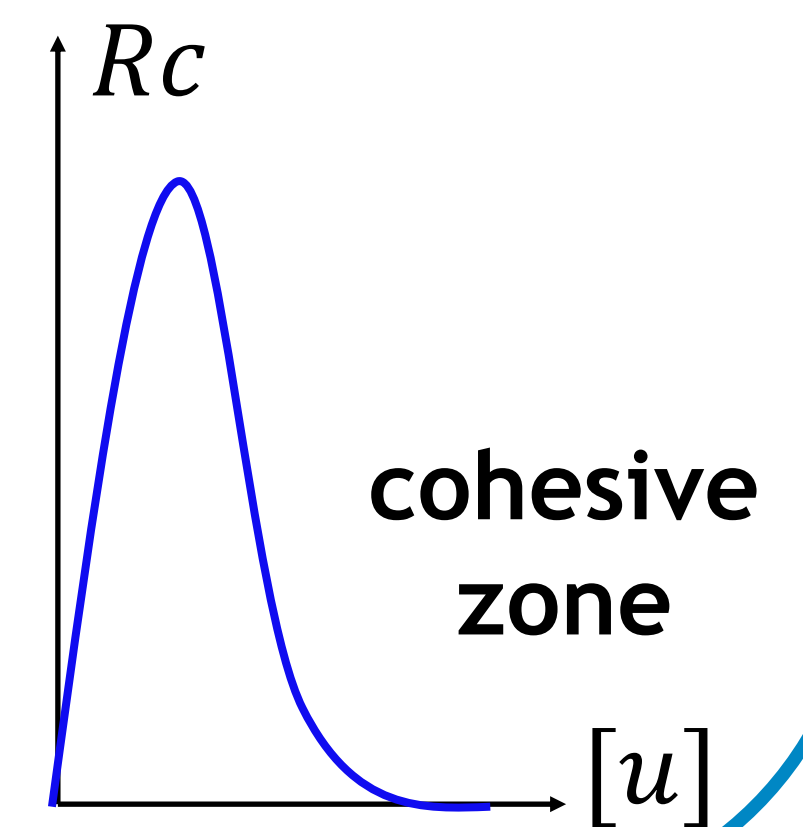
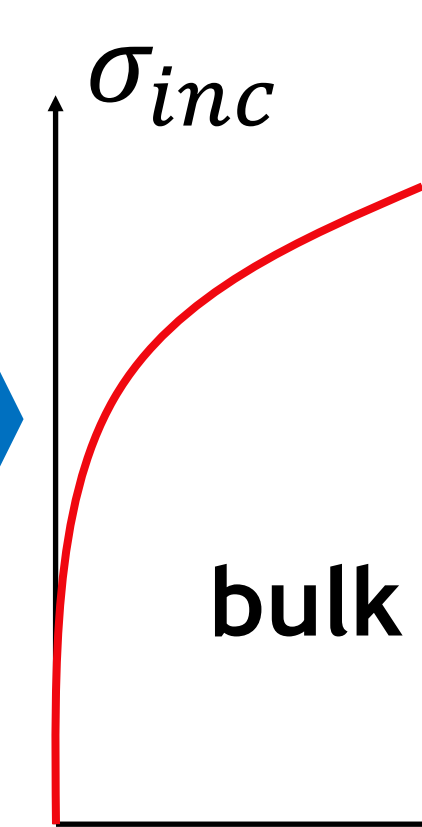
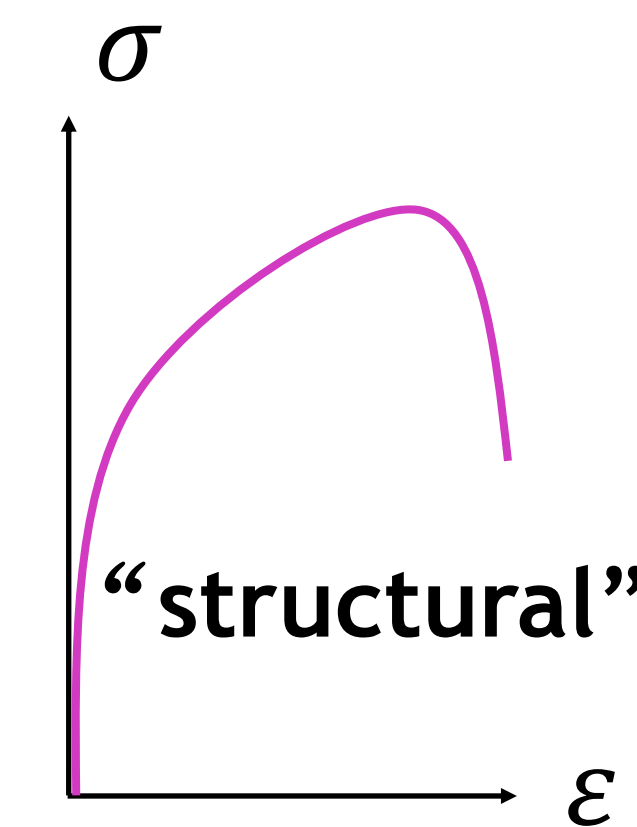
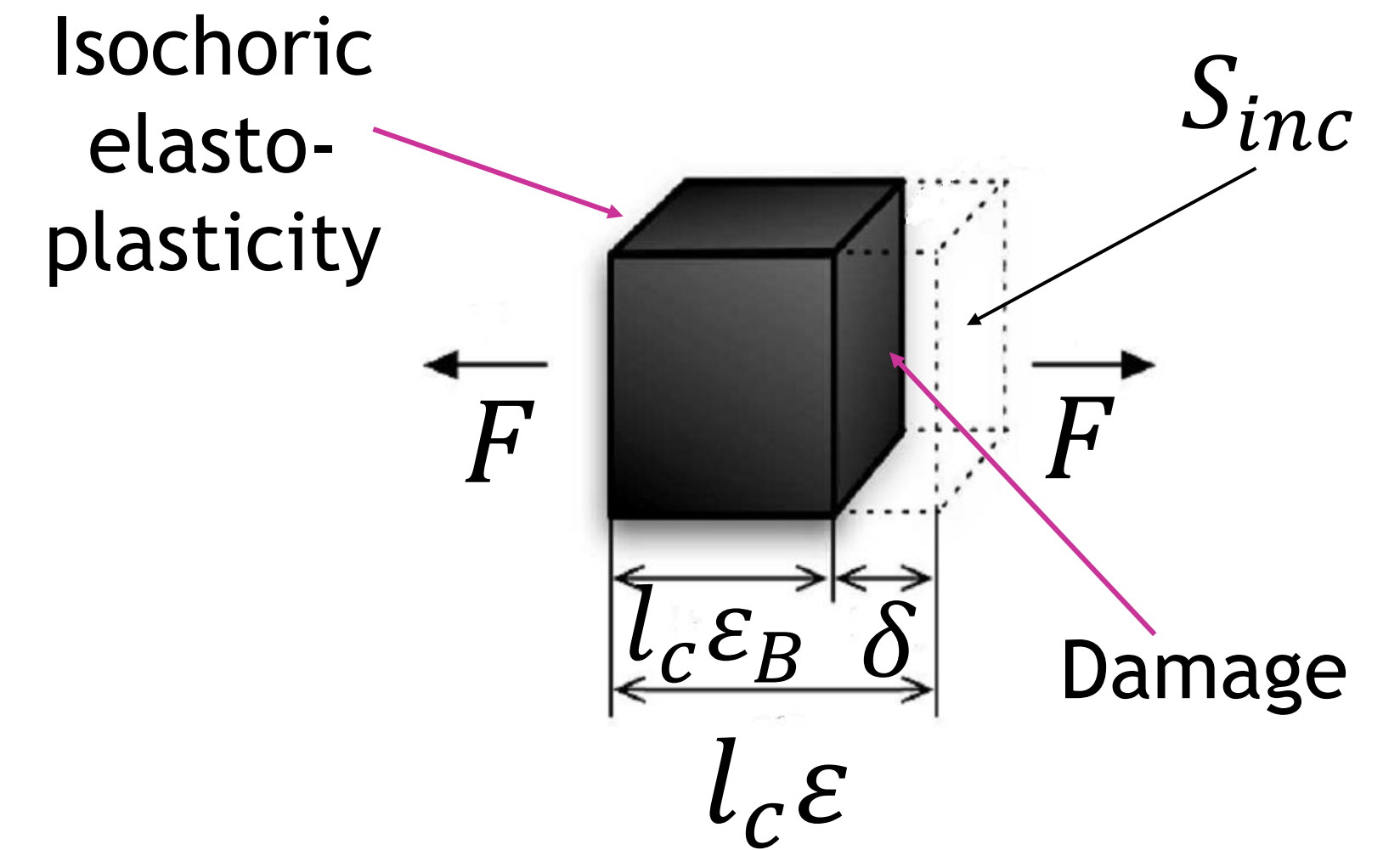
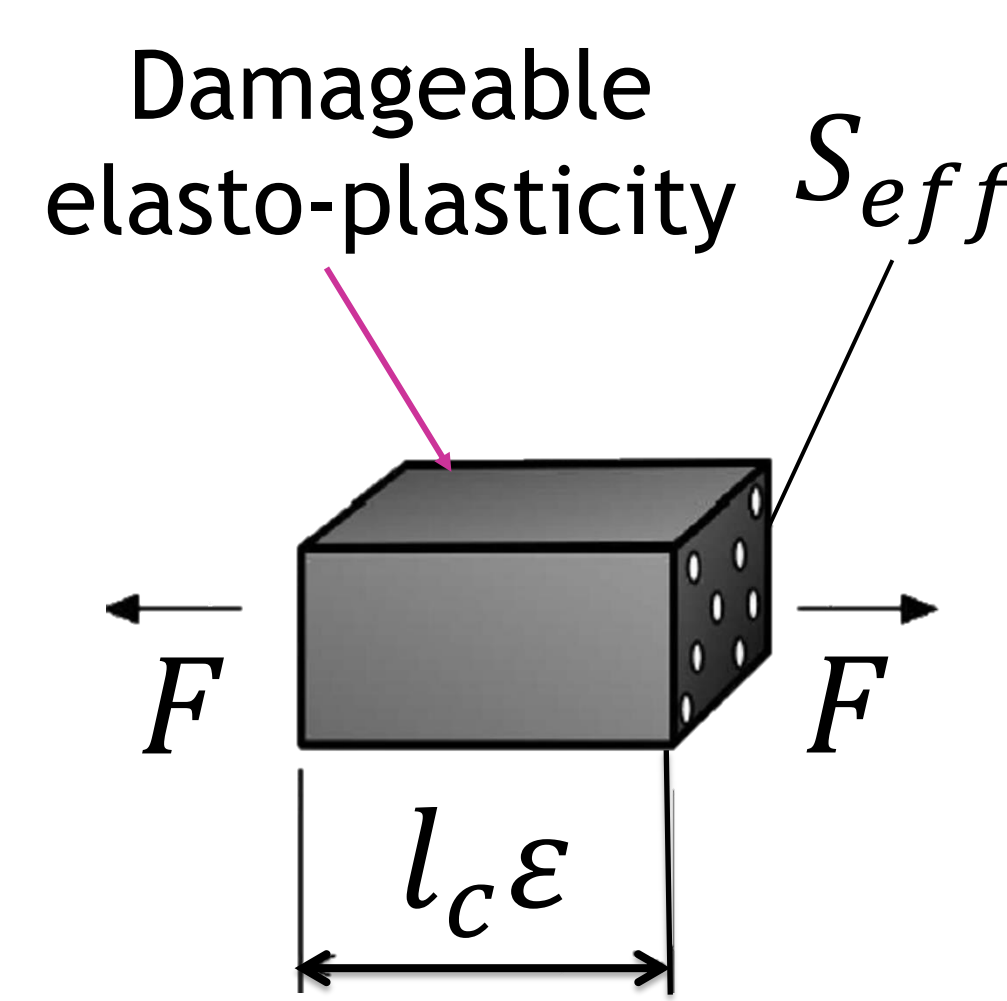
and

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



Displacement field R_1
Full-field measurements

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



Elastic identification

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

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

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

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

Constitutive Equation Gap Method (CEGM)

• $B(p)$ 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.

Plastic identification

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

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

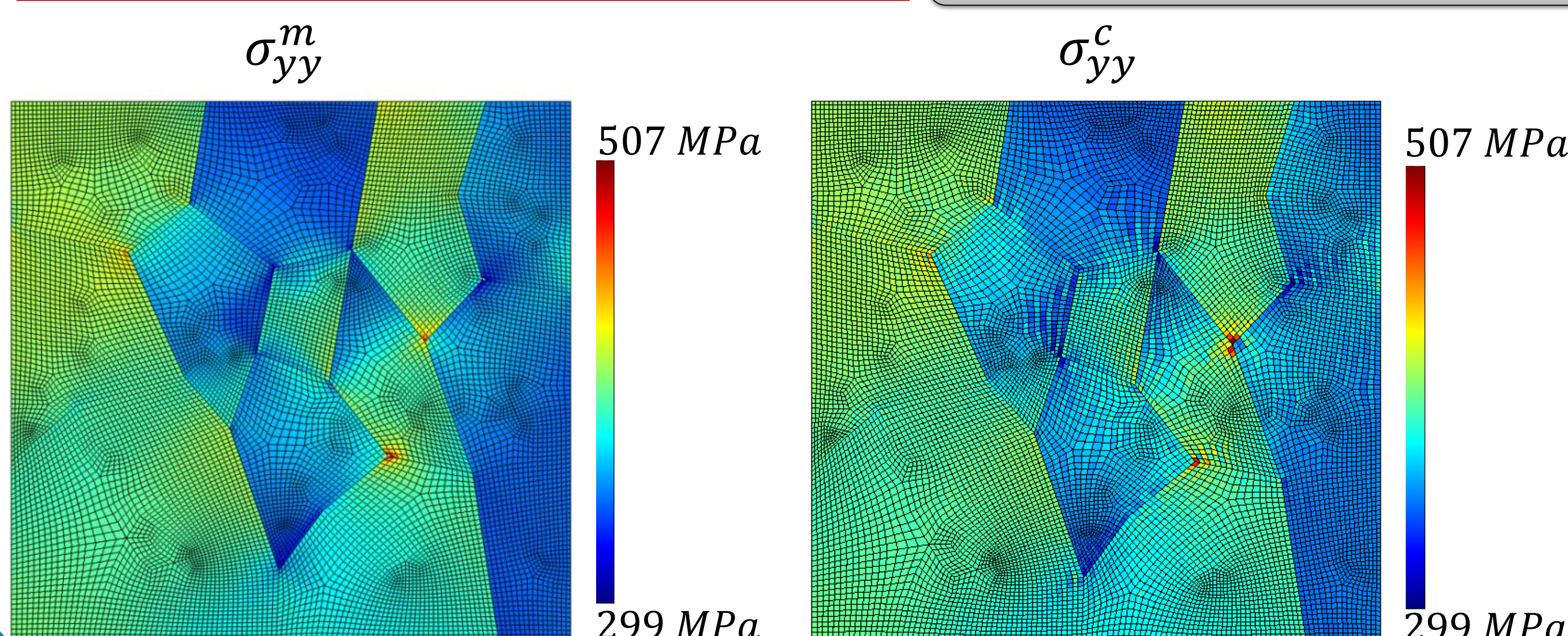
$$K = \frac{\Delta \gamma}{3 + 2 * \Delta \gamma}$$

Rewrite K

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

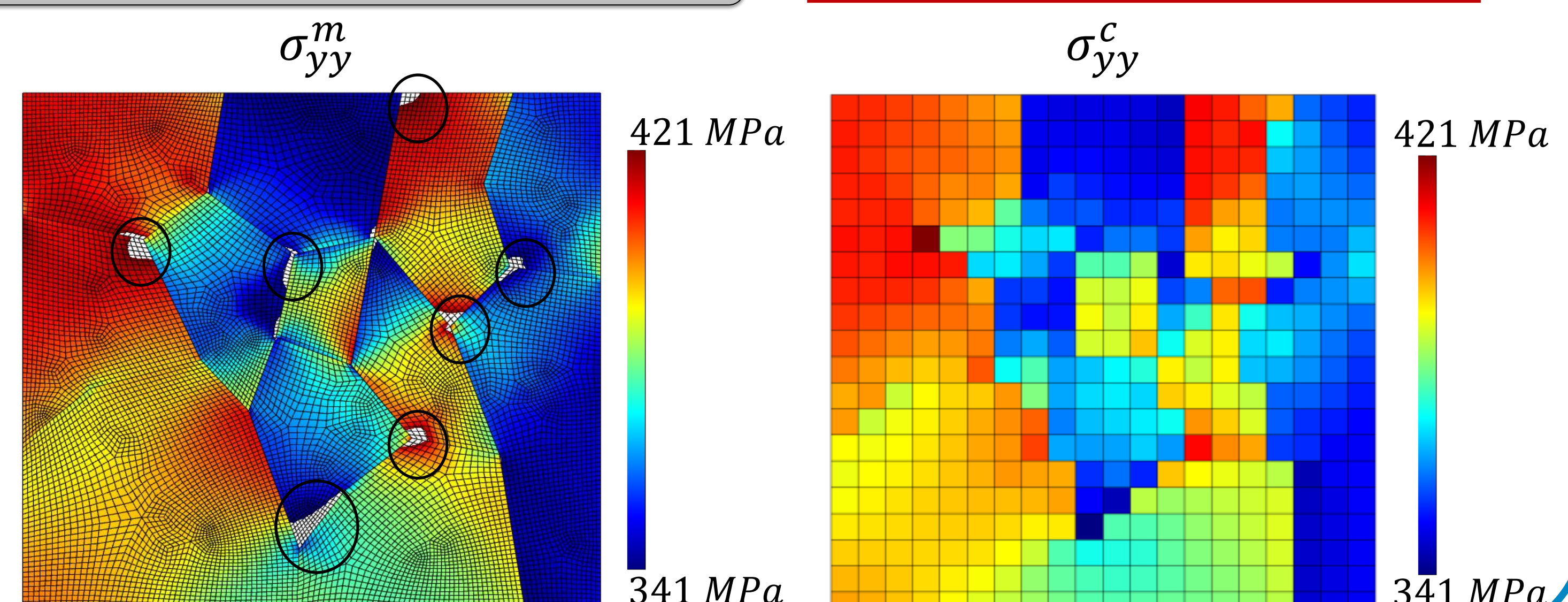
$$\text{with } a = \frac{1}{2k} \text{ and } b = \frac{\sigma_0}{k}$$

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.