Composites Testing and Model Identification, Bristol, UK, 21-23 Sept. 2004

Experimental Identification of a Damage Model for Composites using the Grid Technique Coupled to the Virtual Fields Method

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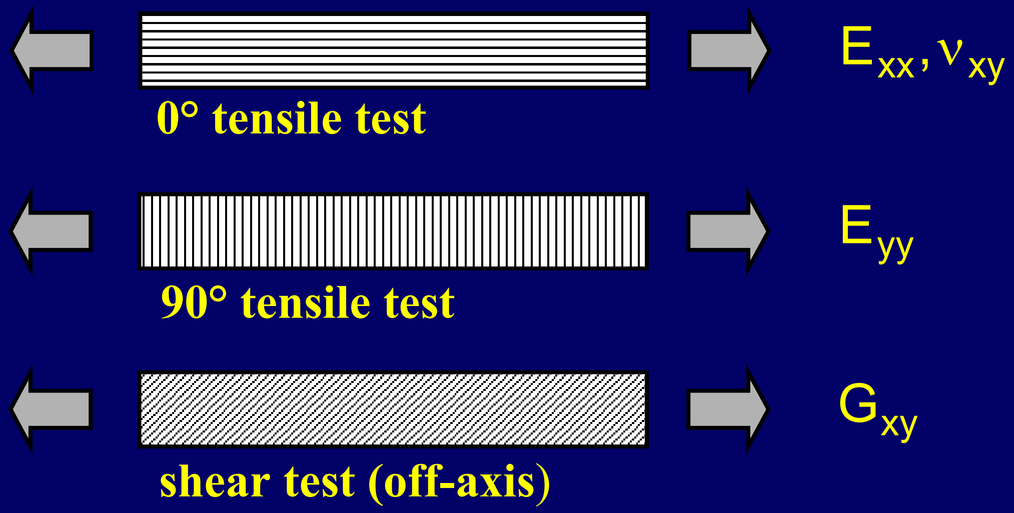
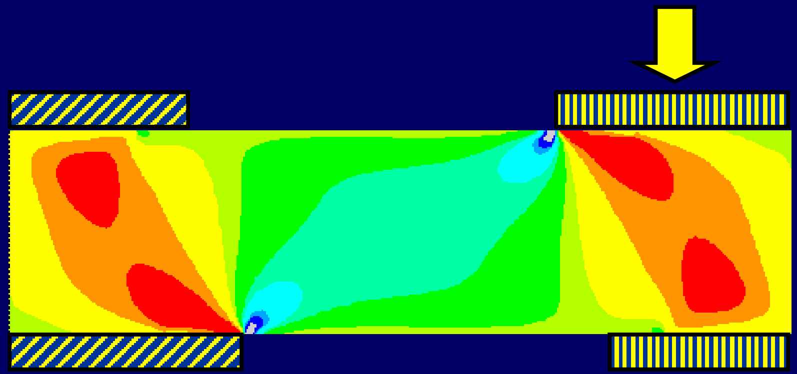
Usual strategy for in-plane orthotropic elastic moduli measurements



3 tests
4 parameters

- Local strain measurements
- Uniform stress fields (closed-form solution)
- Spatial stress distribution

- **Novel** strategy for material parameter identification



Heterogeneous stress fields
(no closed-form solution)
Full-field strain measurements

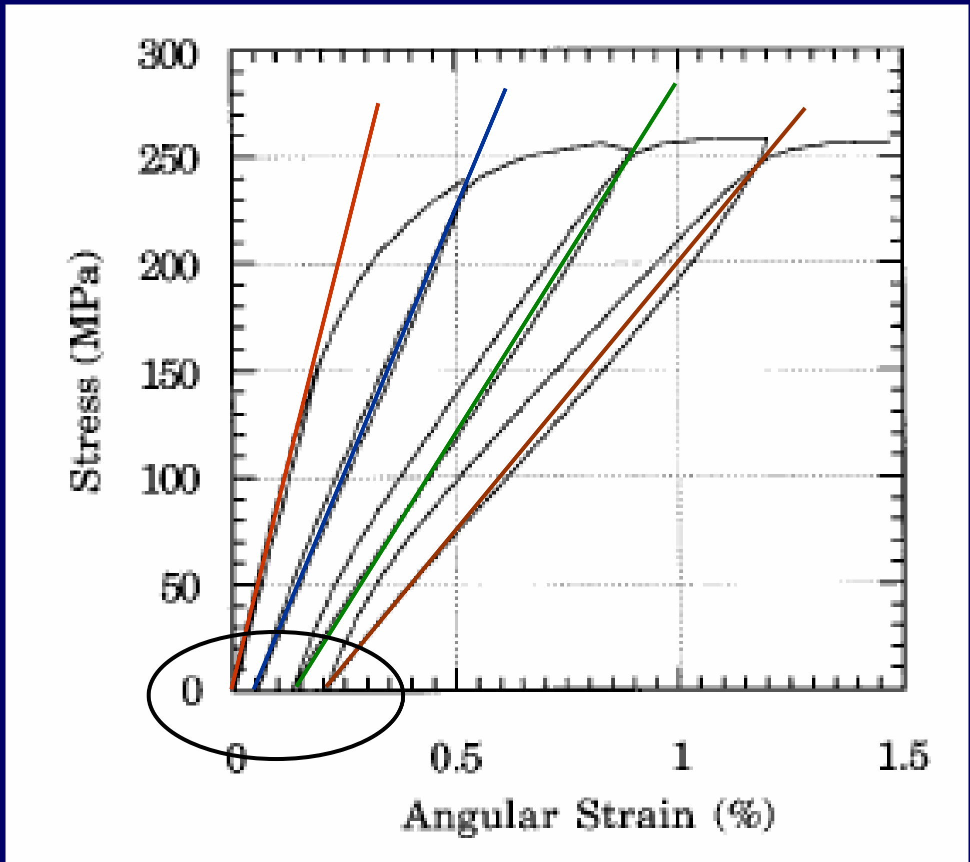
E_{xx}
E_{yy}
ν_{xy}
G_{xy}

1 test

Inverse problem

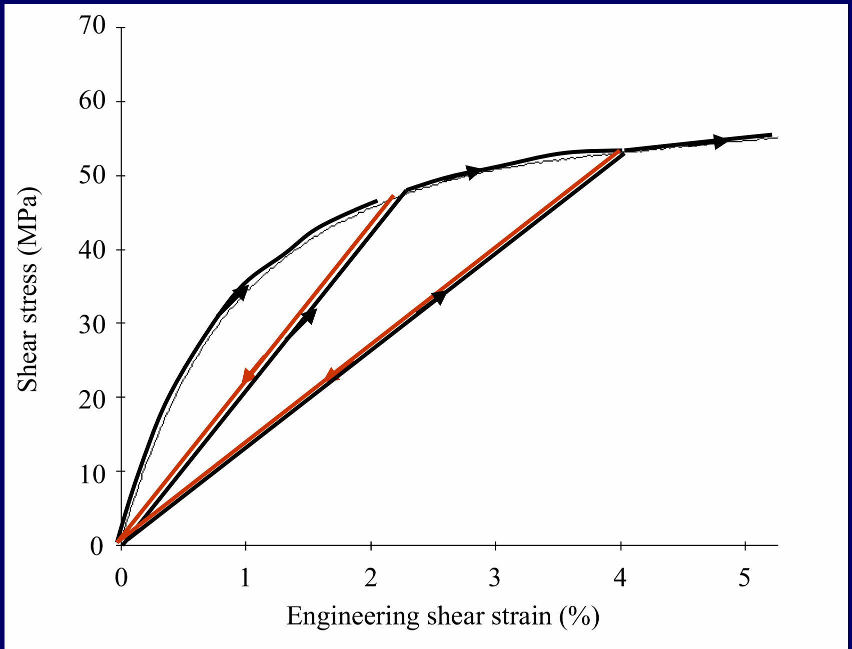
- **FE model updating**
- **Virtual Fields Method**

In-plane shear non linearity



2D Sic/Sic composite (Camus, IJSS, 2000)

In-plane shear non linearity



$$\sigma_s = G_{xy}\varepsilon_s - K\varepsilon_s^3$$

Damage law

$$\sigma_s = G_{xy}^0(1-d)\varepsilon_s$$

$$d = \frac{K}{G_{xy}^0}\varepsilon_s^2$$

Retrieve $E_{xx}, E_{yy}, \nu_{xy}, G_{xy}, K$

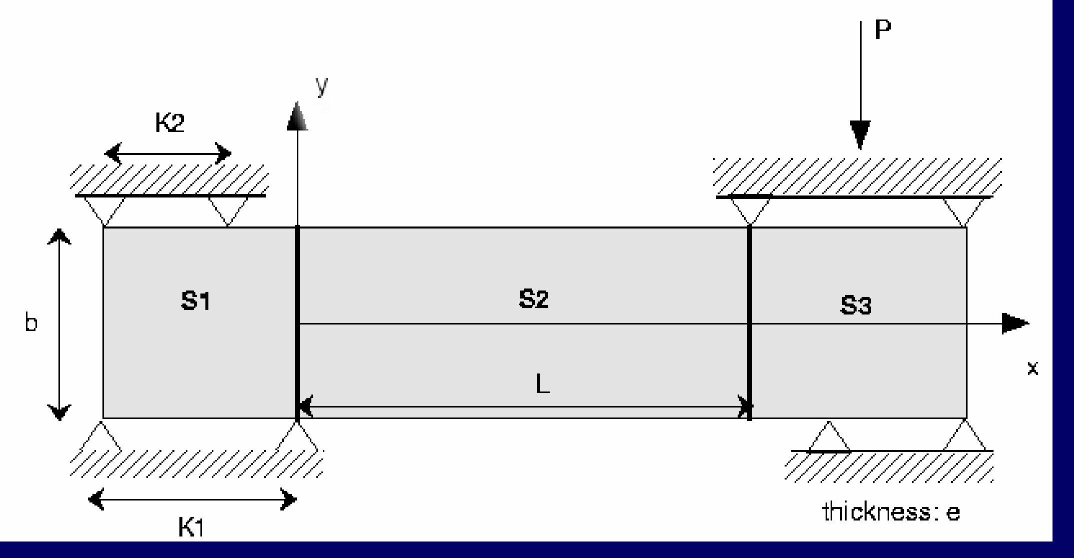
from a heterogeneous strain map

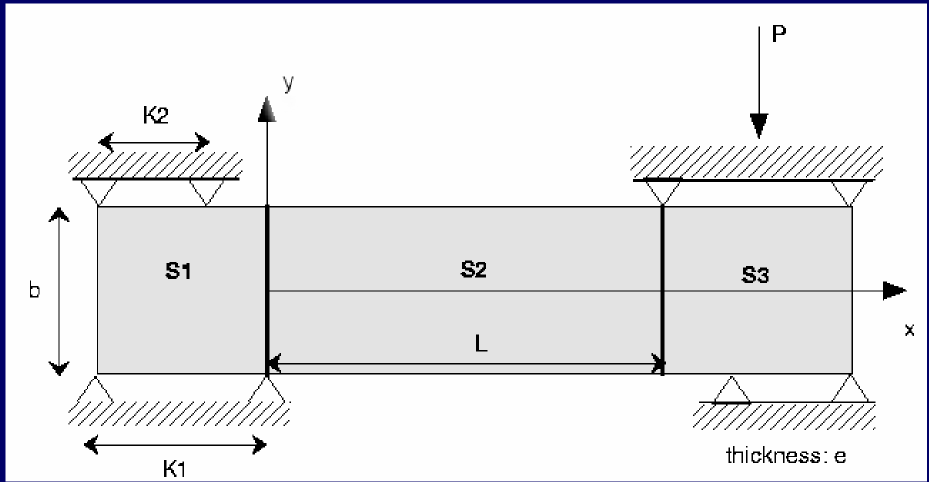
Principle

Global equilibrium of structure

Principle of virtual work $-\int_V \sigma_{ij}\varepsilon^*_{ij}dV + \int_{\partial V} Tu^* dS = 0$

Choice of virtual fields

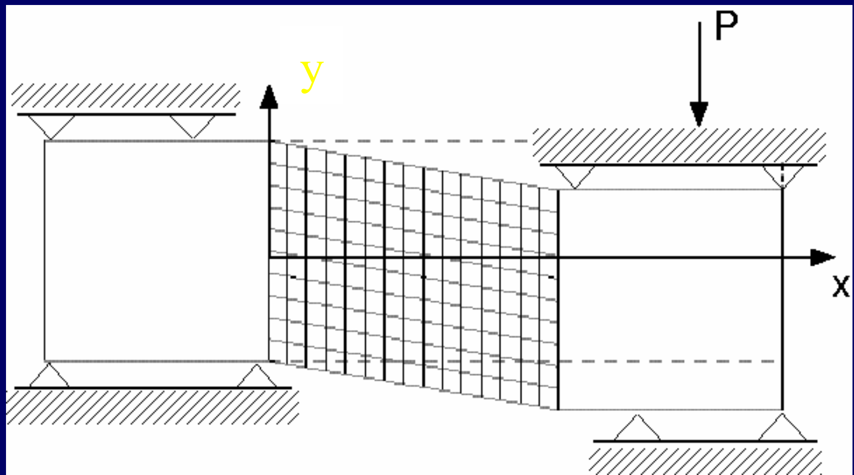




Over S2

$$u_x^* = 0 ; u_y^* = -x$$

$$\varepsilon_x^* = 0 ; \varepsilon_y^* = 0 ; \varepsilon_s^* = -1$$



Uniform virtual shear

$$-\int_V \sigma_{ij}\varepsilon^*_{ij}dV + \int_{\partial V} Tu^*dS = 0$$

Plane stress

$$\int_V \sigma_s dV \Rightarrow t\int_S \sigma_s dS$$

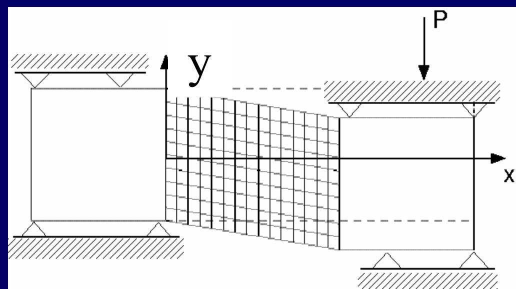
In-plane elastic orthotropy with shear damage

$$\begin{pmatrix}\sigma_x\\ \sigma_y\\ \sigma_s\end{pmatrix} = \begin{bmatrix} Q_{xx} & Q_{xy} & 0\\ Q_{xy} & Q_{yy} & 0\\ 0 & 0 & Q_{ss} - K\varepsilon_s^2 \end{bmatrix}\begin{pmatrix}\varepsilon_x\\ \varepsilon_y\\ \varepsilon_s\end{pmatrix}$$

Material homogeneous

$$t\left(\int_S Q_{ss}\varepsilon_s dS - \int_S K\varepsilon_s^3 dS\right) \Rightarrow t\left(Q_{ss}\int_S \varepsilon_s dS - K\int_S \varepsilon_s^3 dS\right)$$

$$Q_{ss}\int_{S_2} \varepsilon_s dxdy - K\int_{S_2} \varepsilon_s^3 dxdy = \frac{PL}{t}$$



–PL

Need to choose other virtual fields

$$Q_{xx}\int_{S_2}\varepsilon_x\varepsilon_x^*dxdy+Q_{yy}\int_{S_2}\varepsilon_y\varepsilon_y^*dxdy+Q_{xy}\int_{S_2}(\varepsilon_x\varepsilon_y^*+\varepsilon_y\varepsilon_x^*)dxdy$$

$$+Q_{ss}\int_{S_2}\varepsilon_s dxdy-K\int_{S_2}\varepsilon_s^3 dxdy=\frac{u_y^*(L)}{t}$$

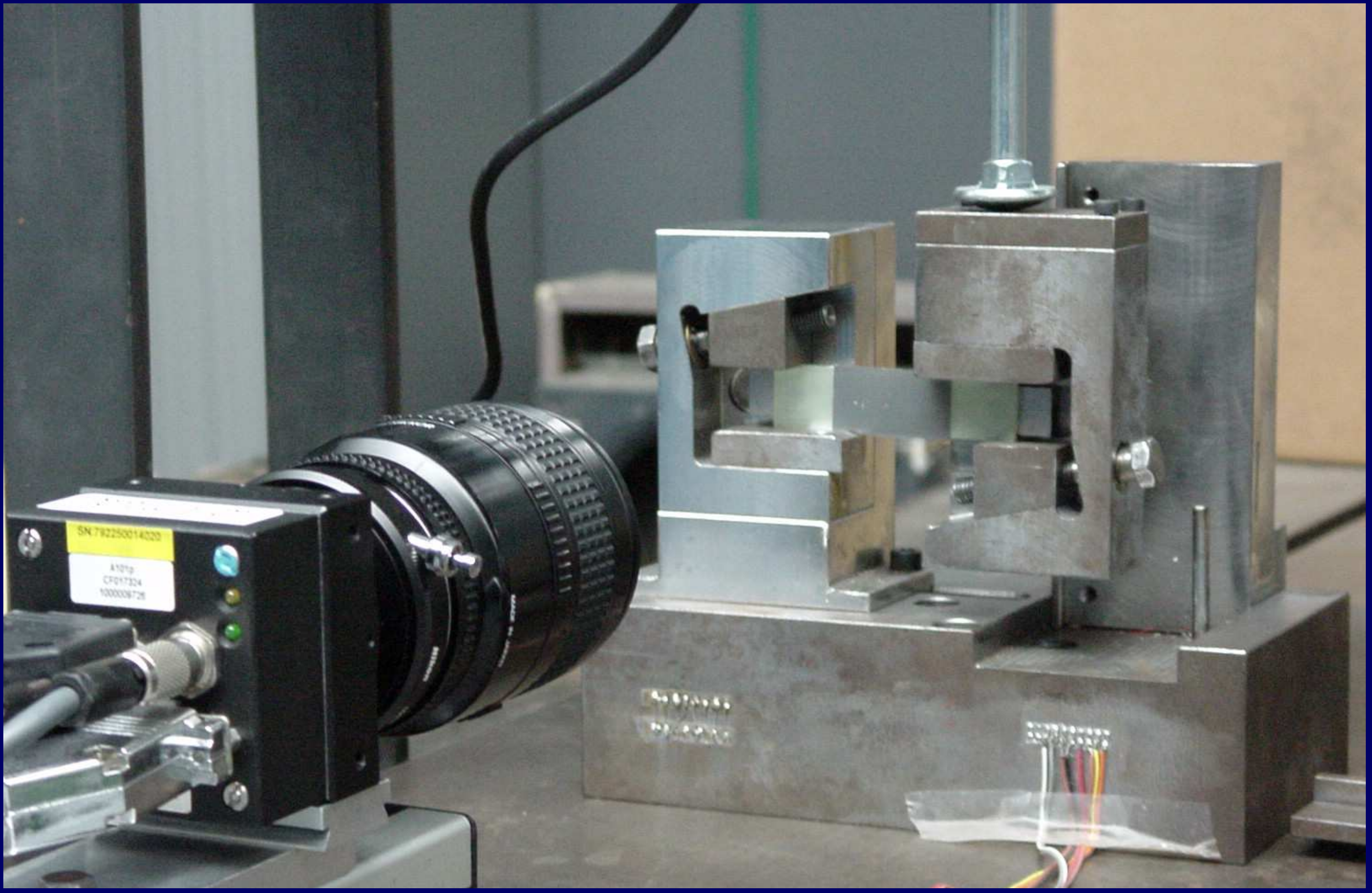
Finally

$AQ=B$ ⇒ $Q=A^{-1}B$ if the fields are « well chosen »

Special virtual fields

$A=I$ ⇒ $Q=B$ optimized to resist to noise in data

Experimental set-up



Material: 0° glass/epoxy composite (2.1 mm thick)

The grid method

Grid glued on the specimen

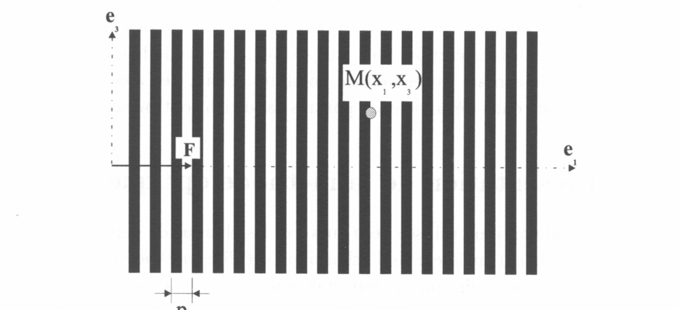


FIG. 4.1 – *Grille utilisée pour l'étude des déplacements dans la direction* e_1.

Spatial phase shifting

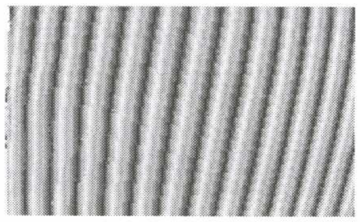


FIG. 4.9 – *Champ de phase initial.*

Phase map (undeformed state)

Loading

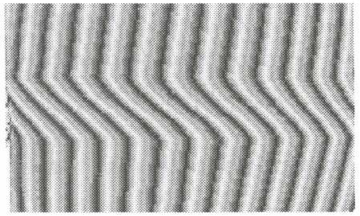
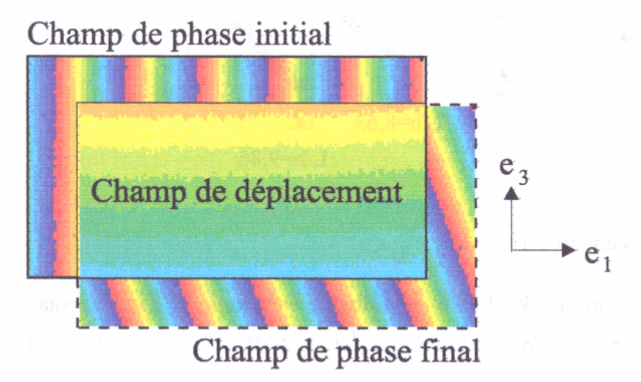


FIG. 4.10 – *Champ de phase final.*

Phase map (deformed state)

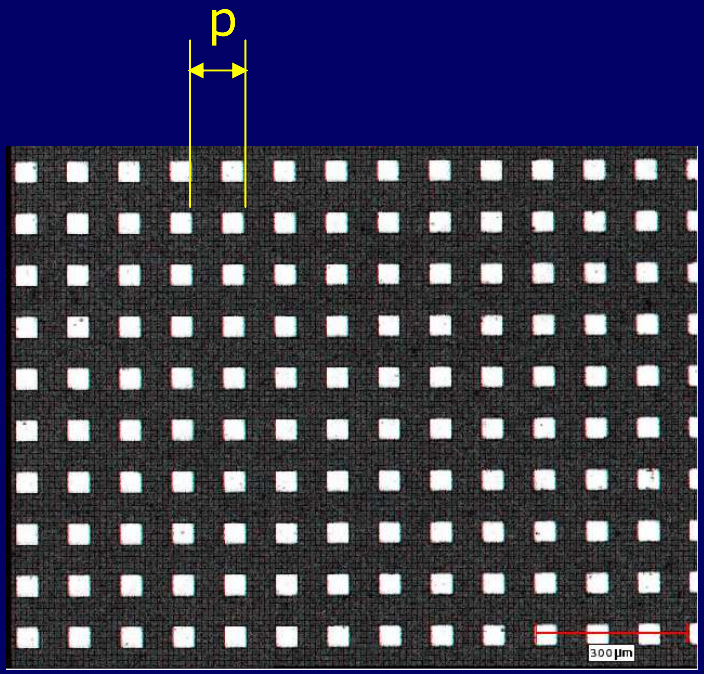
Difference



The grid method

- Printed on a photosensitive film (postscript file)
- Photosensitive layer is transferred onto specimen (white glue), backing film removed

Cross grid of pitch p=100 μm

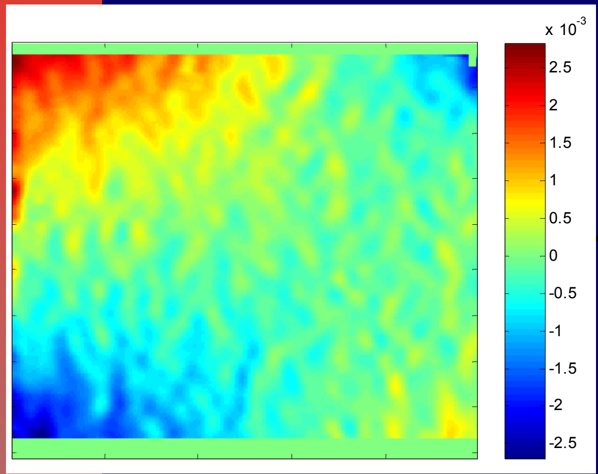


Experimental details

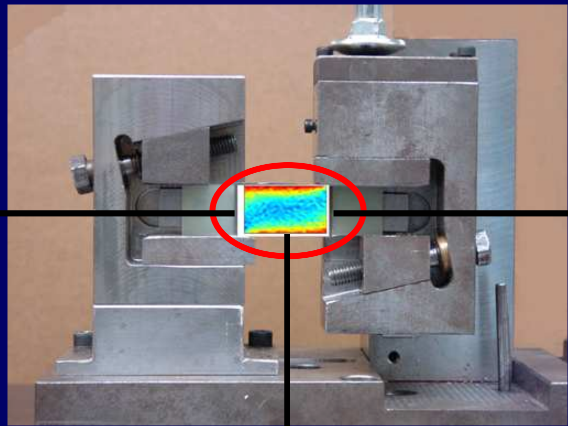
- Digital CCD Camera (8bits, 1280×1024)
- 60 mm focal lens
- Frangyne software (Prof. Y. Surrel)
- Field of view: 30 mm by 20 mm
- 4 pixels /period
- Smoothing phase maps: 33 x 33, twice
- Differentiation: 33 x 33 pixels

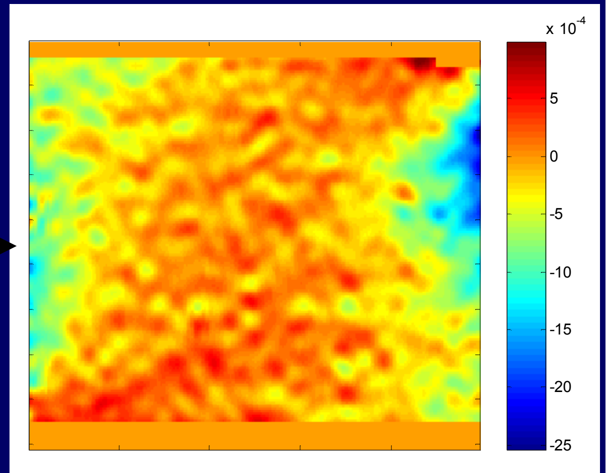
Spatial resol. in displacement Δx	Resol. in diplacement σ_u	Spatial resol. in strain $\Delta\varepsilon$	Resol. in strain σ_ε
200 µm	0.60 µm (p/170)	1.4 mm	120 microdef.

Strain maps

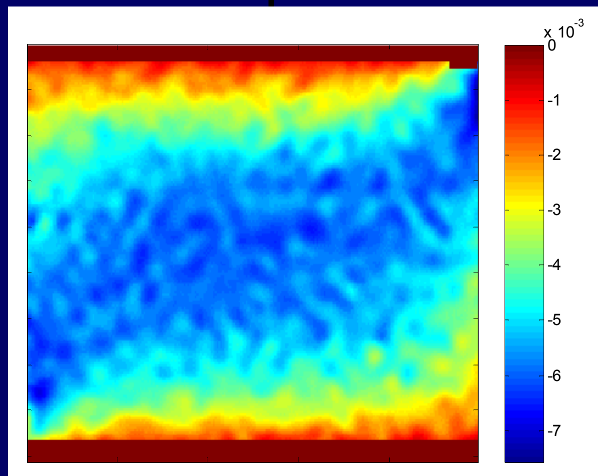


ε_x





ε_y



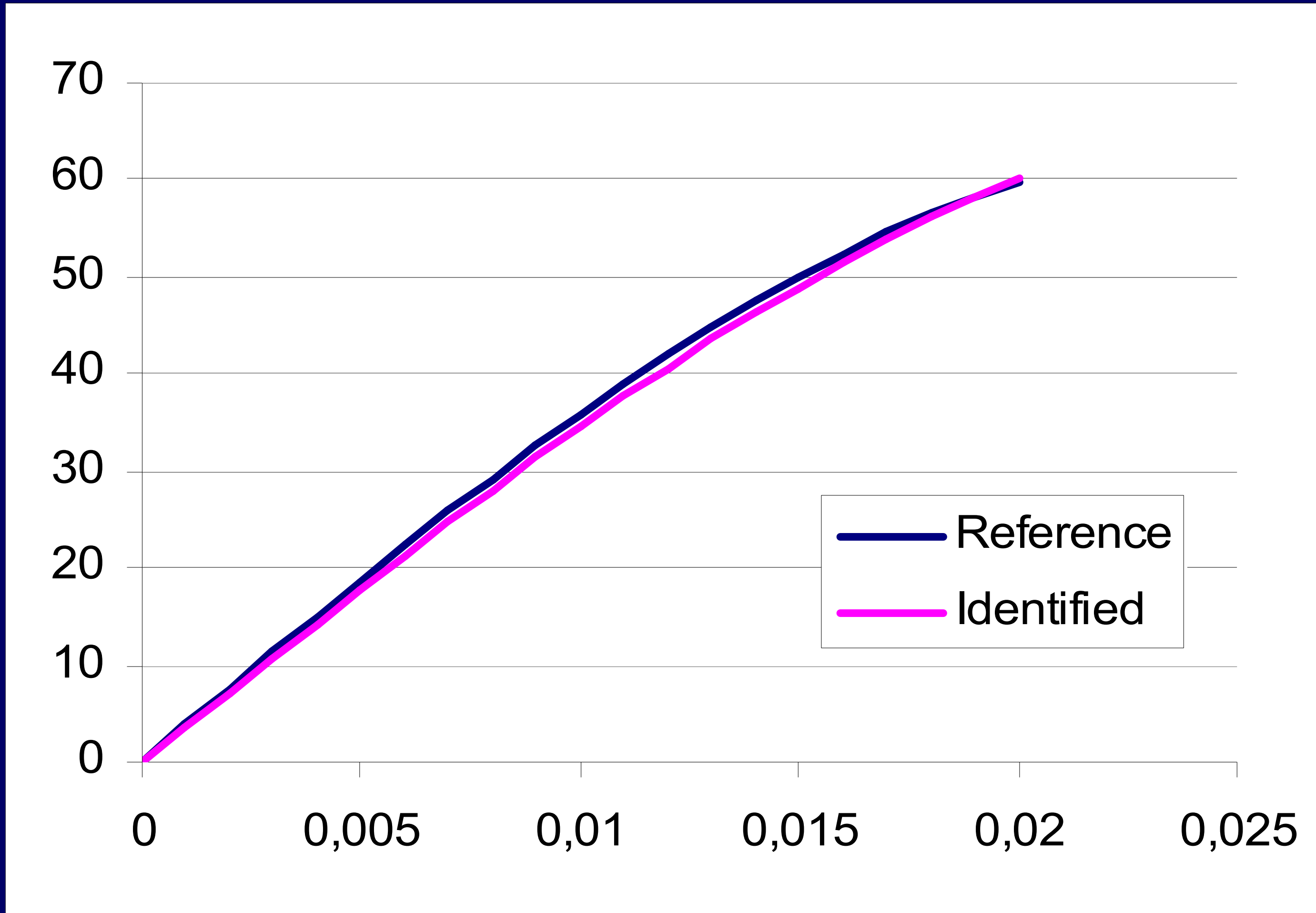
ε_s

Identification results

- Special virtual fields

	Q_{xx}	Q_{yy}	Q_{xy}	Q_{ss}	K
Reference (GPa)	44.9	12.2	3.86	3.78	1990
Coeff. var (%)	0.7	2.8	2.4	7.3	31
Identified (GPa)	56	27	-	3.6	1500
Rel. diff. (%)	25	130	*	-5	-25

In-plane strain response



Conclusions

- VFM: process strain maps
- VFM: Material non-linearity
- Good results if information there
- Problem: what test?

Perspectives

- Fibres at an angle (45° ?)
- Design of new tests adapted to VFM
- Implement more sophisticated constitutive models