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Laboratoire de Mécanique et Procédés de Fabrication

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Châlons en Champagne

Identification of the through-thickness rigidities of a thick laminated composite tube

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CompTest 2004

Department of Aerospace Engineering

Outlook

- Thick-composite testing
- The Virtual Fields Method
- Full-field measurements
- Identification results
- Summary and future work

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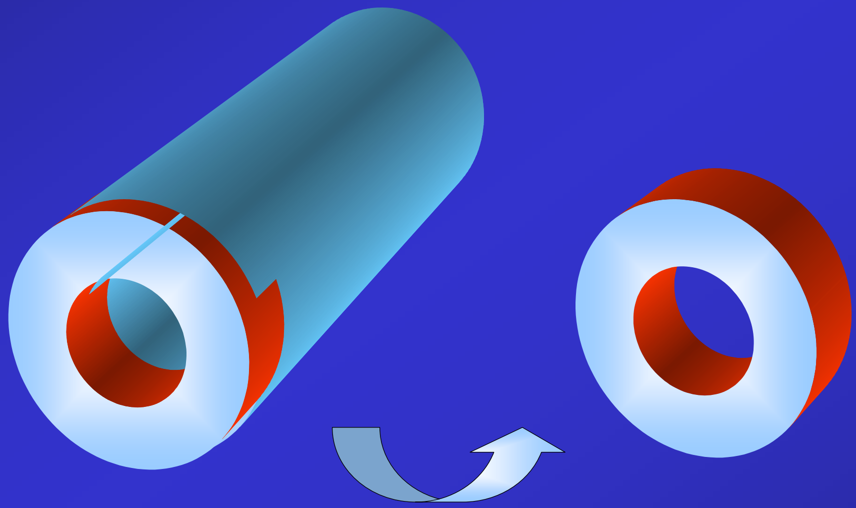
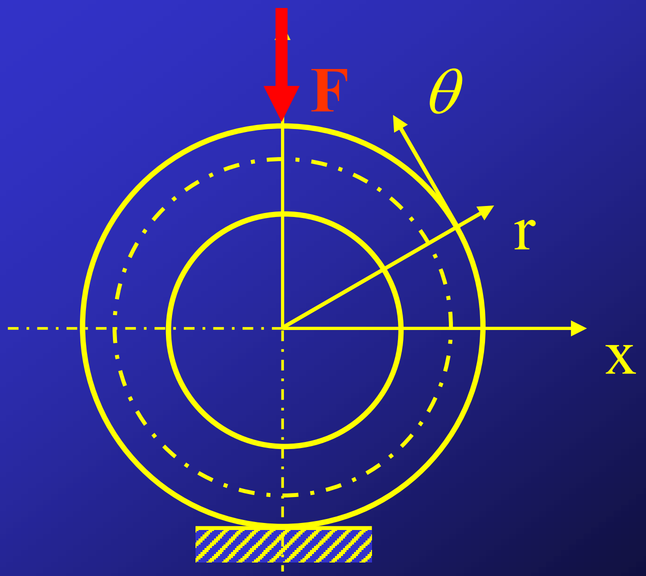
Thick composites problematic

- Recent use of thick laminated composite materials
- Need of the through-thickness mechanical properties
- Unsuitability of standard tests
- Development of a novel experimental procedure

Thick laminated tubes

- Tubes obtained by filament winding
- Ring coupons tested by diametral compression





Constitutive equations

- Elastic cylindrical orthotropic:

$$\begin{pmatrix} \sigma_r \\ \sigma_\theta \\ \sigma_s \end{pmatrix} = \begin{bmatrix} Q_{rr} & Q_{r\theta} & 0 \\ Q_{r\theta} & Q_{\theta\theta} & 0 \\ 0 & 0 & Q_{ss} \end{bmatrix} \begin{pmatrix} \varepsilon_r \\ \varepsilon_\theta \\ \varepsilon_s \end{pmatrix}$$

→ 4 unknowns

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Procedure

Diametral compression test → Heterogeneous strain field

Full-field measurements → Strain field

Virtual Fields Method → Stiffness identification

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Principle

- Introduced by GREDIAC (1989)
- Heterogeneous strain field
- Simultaneous identification of four stiffnesses with a single mechanical test
- Based on the Principle of Virtual Work:

$$e\int_{S} \underline{\underline{\sigma}} : \underline{\underline{\varepsilon}}^{*} dS = \int_{S_f} \vec{T}(M)\,\vec{u}^{*}(M)\,dS$$

Equations

$$Q_{rr}.e\int_S \varepsilon_r \varepsilon_r^* dS + Q_{\theta\theta}.e\int_S \varepsilon_\theta \varepsilon_\theta^* dS + Q_{r\theta}.e\int_S \left(\varepsilon_r \varepsilon_\theta^* + \varepsilon_\theta \varepsilon_r^*\right) dS$$
$$+ Q_{ss}.e\int_S \varepsilon_s \varepsilon_s^* dS = \int_{S_f} \vec{T}(M)\vec{u}^*(M) dS$$

4 virtual fields

$$[\mathbf{A}]\times(\mathbf{Q}) = (\mathbf{B})$$

Linear system of equations

Virtual fields

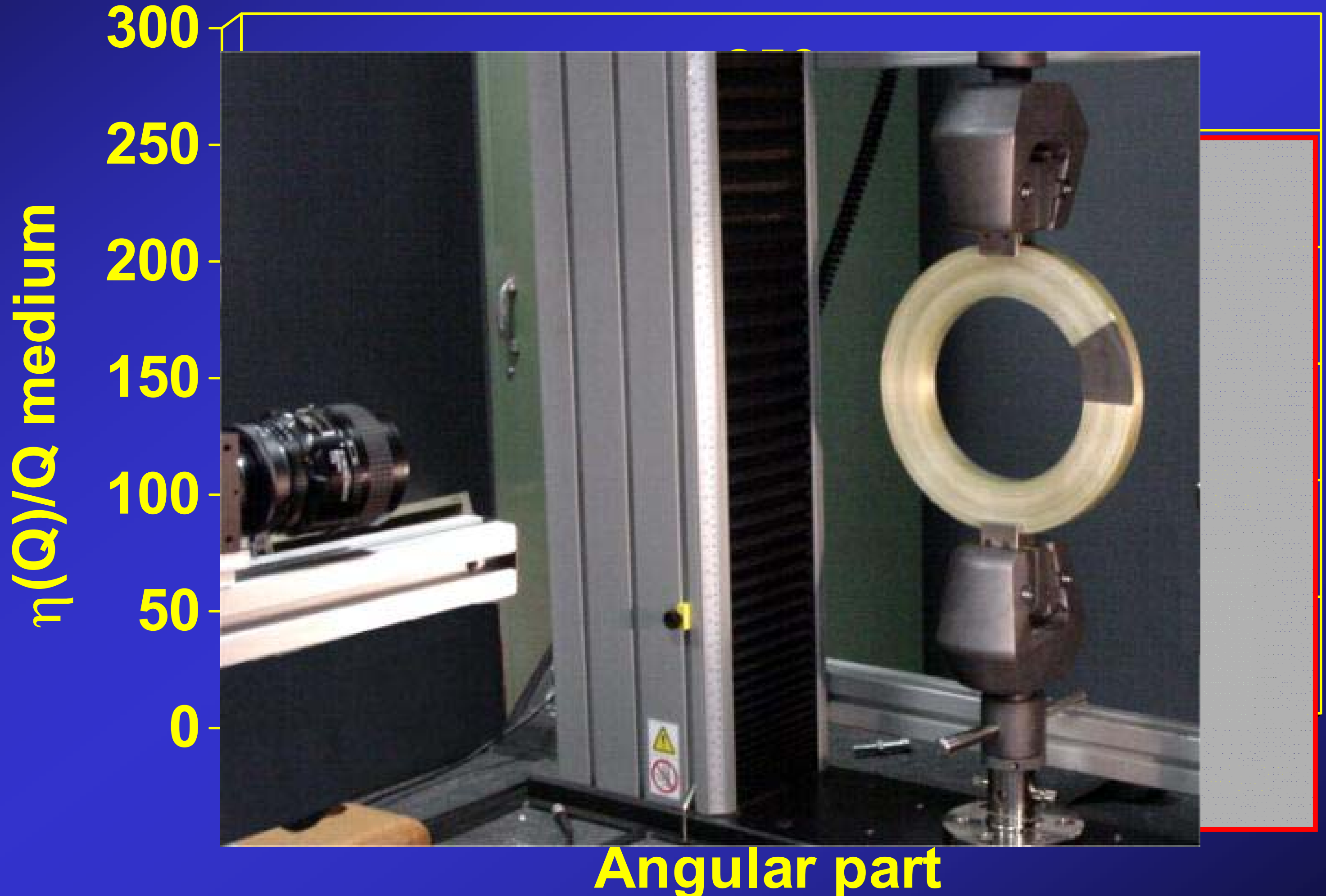
- Field n°1: $$\begin{cases} u_x^* = 0 \\ u_y^* = (\theta - \theta_0) \end{cases}$$
- Field n°2: $$\begin{cases} u_x^* = (\theta - \theta_0)(\theta - \theta_1) \\ u_y^* = (\theta - \theta_0) \end{cases}$$
- Field n°3: $$\begin{cases} u_x^* = \left[(\theta - \theta_0)(\theta - \theta_1)\right] \times x^2 \\ u_y^* = 0 \end{cases}$$
- Field n°4: $$\begin{cases} u_x^* = \left[(\theta - \theta_0)(\theta - \theta_1)\right] \times x \\ u_y^* = 0 \end{cases}$$

Region of interest

- The region of interest is chosen according to the identifiability of the unknown stiffnesses.

- Finite elements model
  - $E_{rr} = 10$ GPa
  - $E_{\theta\theta} = 40$ GPa
  - $\nu_{\theta r} = 0.3$
  - $G_{r\theta} = 4$ GPa

Region of interest



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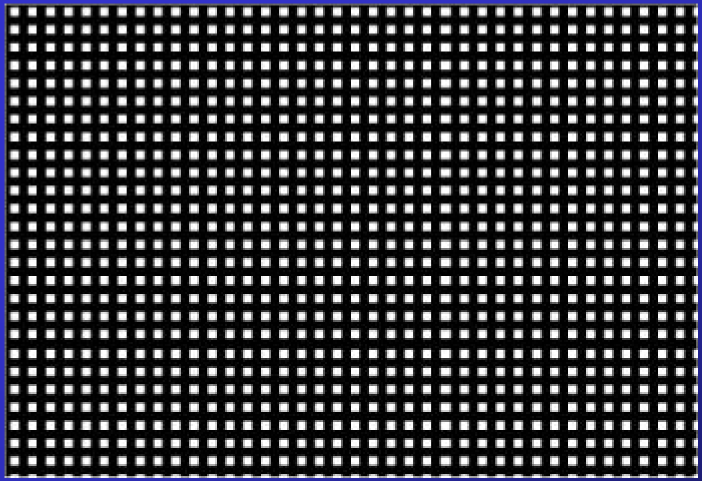
The grid method

- Full-field optical measurement technique

$\Rightarrow$ Based on the use of a spatial carrier encoding the observed surface

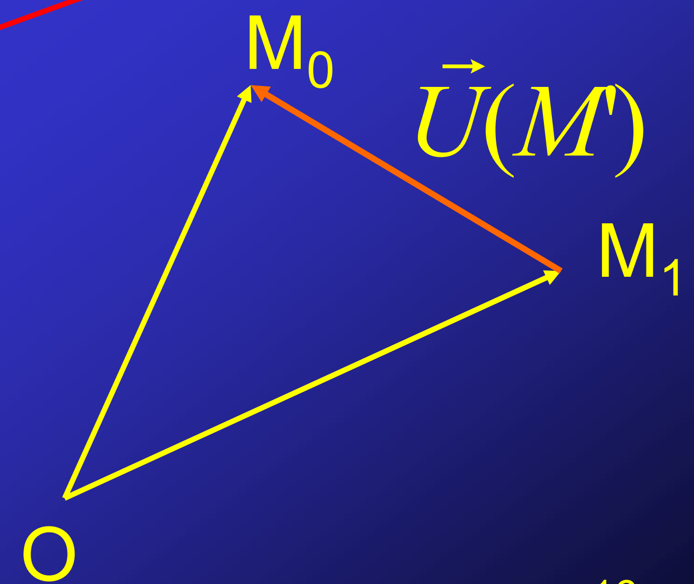


The grid method

$$I(x,y) = A(x,y)\left[1+\gamma(x,y)\mathrm{Frng}\left(\frac{2\pi x}{p}+\varphi(x,y)\right)\right]$$

$$u_x(x,y) = \frac{-p}{2\pi}\varphi_x(x,y)$$

$$u_y(x,y) = \frac{-p}{2\pi}\varphi_y(x,y)$$



Strain measurement

- Numerical differentiation of displacement fields fitted by 4th degree polynomials.

$$\varepsilon_{ij} = \frac{1}{2}\left[\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right]$$

$$\varepsilon(x) = \frac{u(x+\Delta x)-u(x)}{\Delta x}$$

Measurement parameters

- Pitch of the grid: p = 480 *μm*
- Sampling: 6 pixels / period
- Spatial resolution: 5 mm
- Displacement resolution: 2.3 μm

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Measured displacement fields

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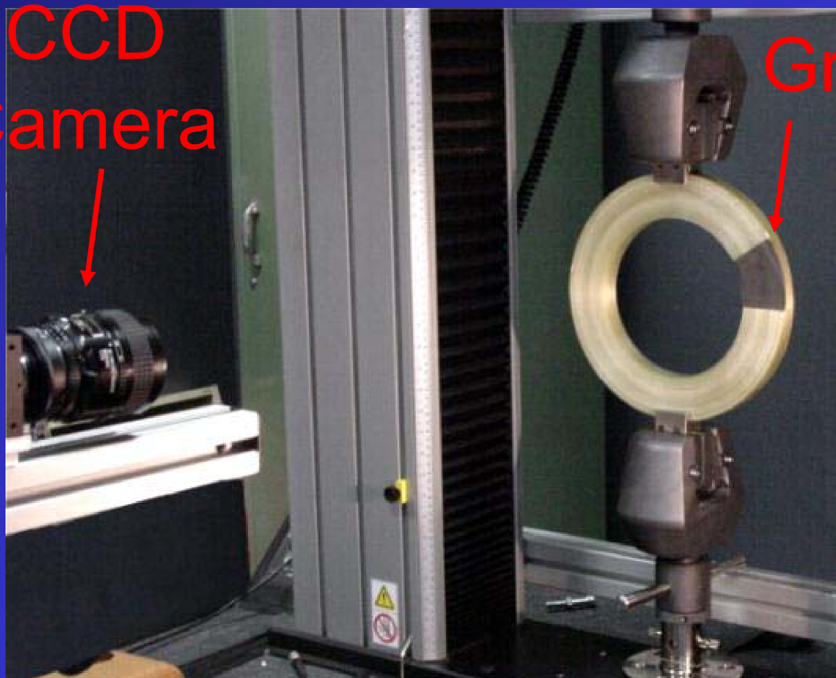
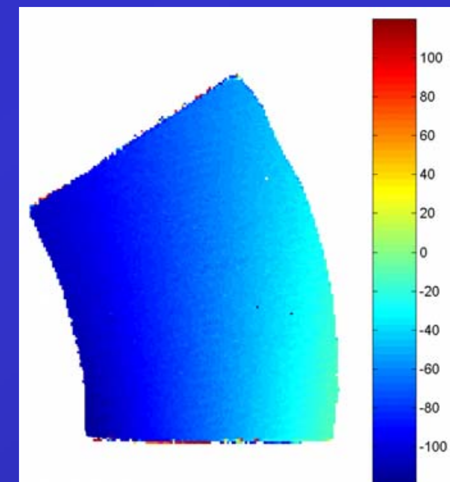
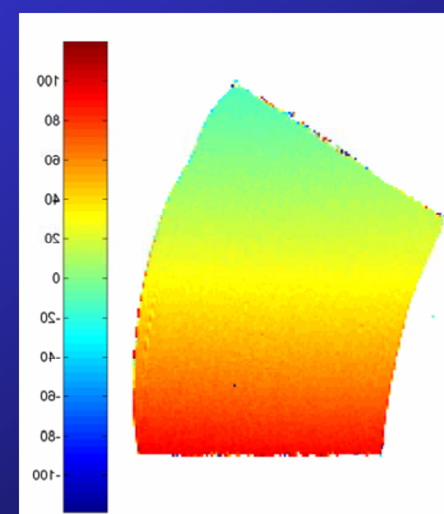


F = 20000 N

u_x:

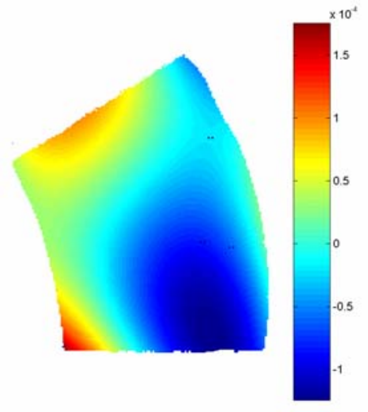


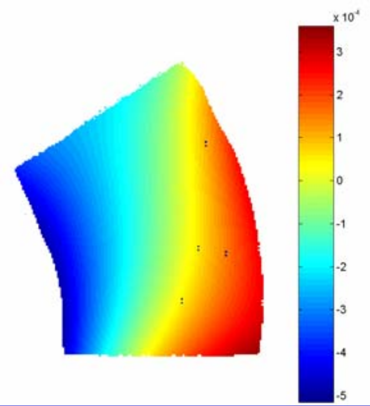
u_y:

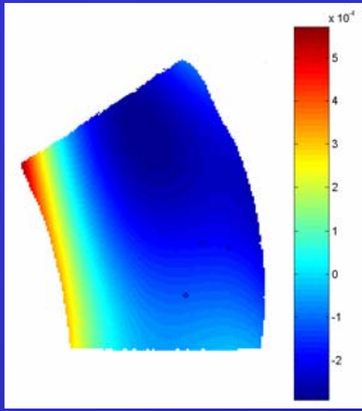


Strain fields

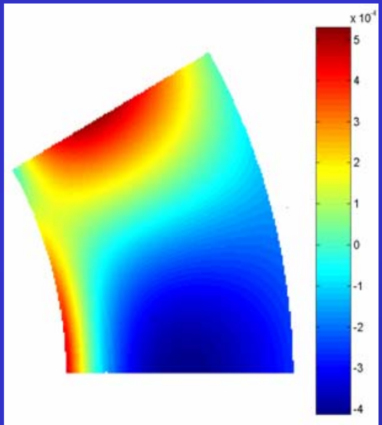
Experimental:

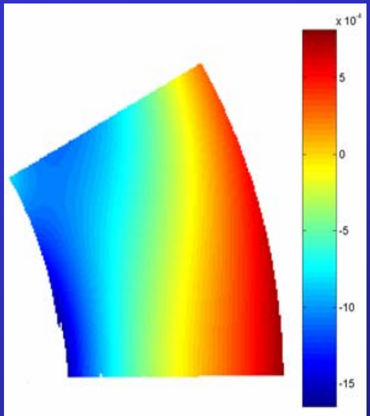


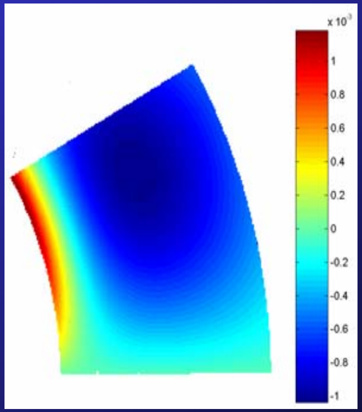




Numerical modelling:







ε_x ε_y ε_s

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Large errors in the first identified moduli

	E_{rr} (GPa)	$E_{\theta\theta}$ (GPa)	$\nu_{\theta r}$	$G_{r\theta}$ (GPa)
Test n°1	95	342	0.37	18.6
Test n°2	266	630	0.29	26
Reference :	10	40	0.3	4

Origin of the discrepancies

- High sensitivity to out of plane displacements.
- Relevancy of the plane stress assumption.
- Symmetry of strain distribution.

Solutions regarding out of plane displacements

- Need to monitor parasitic motions of the loading machine.
- Possible use of an optical technique which is unsensitive to out of plane displacements: ESPI.

New identified moduli

		E_{rr} (GPa)	$E_{\theta\theta}$ (GPa)	$\nu_{\theta r}$	$G_{r\theta}$ (GPa)
Grid	Aver.	5.5	50	0.27	7.4
	CoV.	80%	16%	140%	35%
ESPI		1.5	21.7	0.86	8.5
Reference :		10	40	0.3	4

Discussion

- Results consistent with the reference values.
- Low repeatability and stability in the results.
- Deviation of ESPI results.
- Suitability of the specimen shape and loading configuration ???

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Summary

- Simple and efficient identification procedure for composite tubes.

  1 single test $\Rightarrow$ 4 moduli

- Future work:

  Design of a mechanical test better suited to the application of this procedure.