Experimental Investigation of Composite Patches with a Full-Field Measurement Method

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Aeronautical context

Classical maintenance problem:

Three technological solutions:

Appearance of damage symptoms

Change of the damaged components

Repair with bonded composite patches [Baker, 1984]

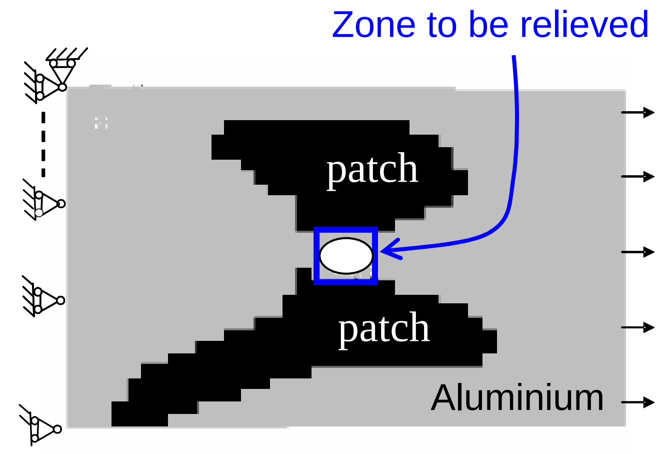
?

Preventive reinforcement with bonded composite patches

Global project

Optimization of **shape**, **location** and **stacking sequence**, by genetic algorithm

[Mathias, 2004]



Analysis of the reinforcement:

Shear stress concentration in the **adhesive** !

Aim of this presentation:

Experimental assessment of the stress distributions in the composite and in the adhesive

OUTLINE:

1. REINFORCEMENT MODELLING

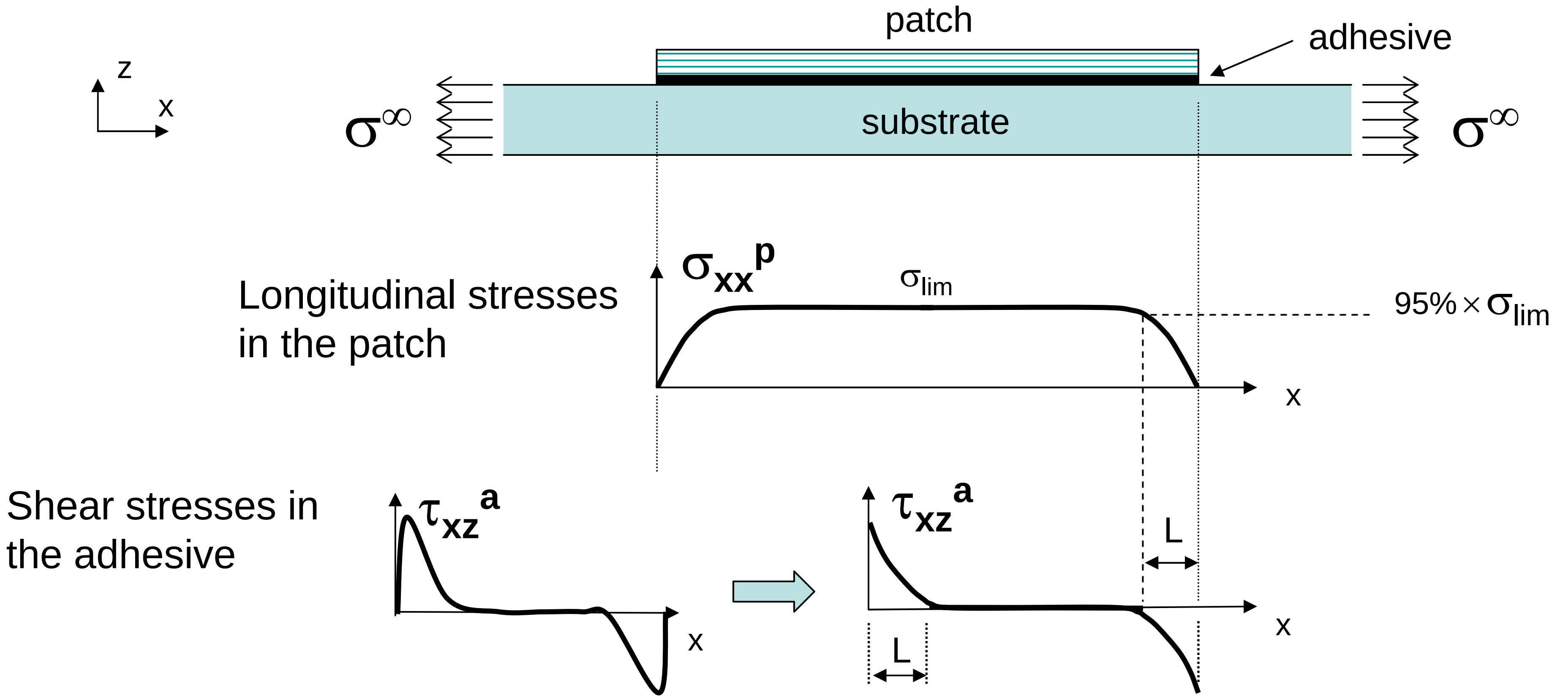
2. EXPERIMENTAL SETUP

3. RESULTS OF TENSILE TESTS

4. CONCLUSION

Unidimensional modelling

Illustration of the longitudinal response



Equilibrium equation + elasticity

Stresses:

$$\sigma_{xx}^{p}(x) = K_1 e^{\gamma x} - \left(\frac{\beta}{\gamma^2} + K_1\right) e^{-\gamma x} + \frac{\beta}{\gamma^2}$$

β, γ and K_1 = f (*dimensions*, *elastic parameters*, *load)*

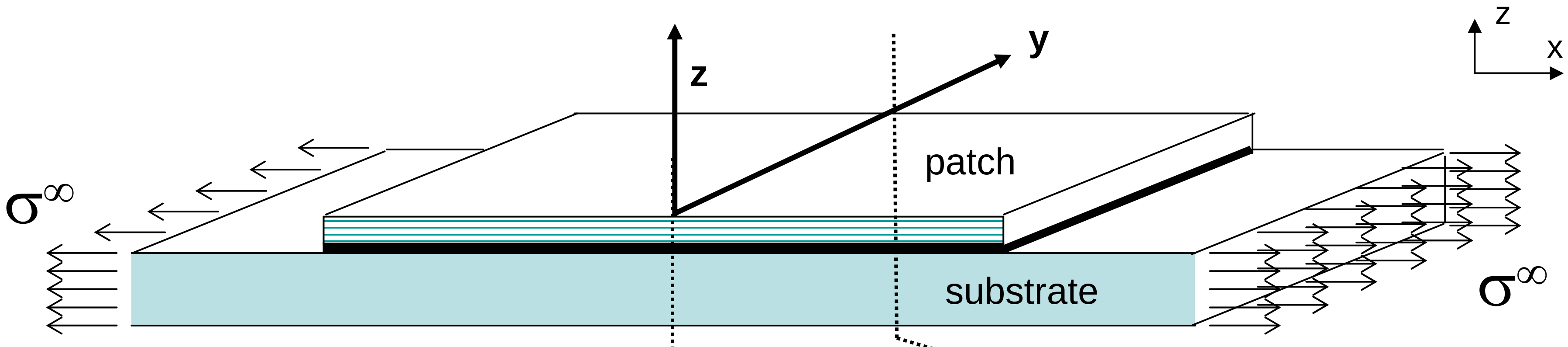
Transfer length corresponding to **95 % of the limit stress** in the patch:

$$L_{95\%}^{\text{long.}} \approx \mathbf{3} / \gamma$$

Displacements:

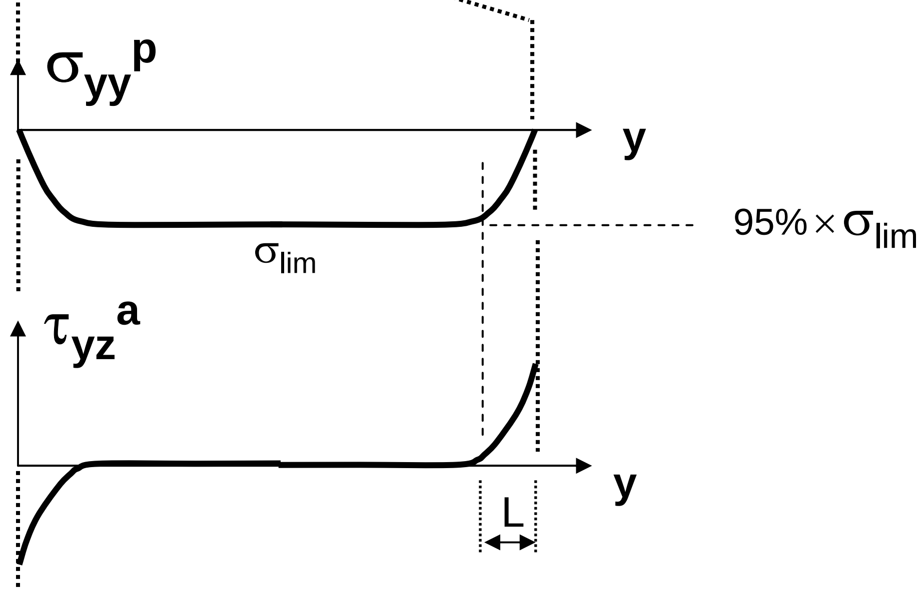
$$u_x^{p}(x) = \frac{1}{\gamma}\frac{K_1}{E_x^p} e^{\gamma x} + \frac{1}{\gamma}\left(\frac{\beta}{E_x^p \gamma^2} + \frac{K_1}{E_p}\right) e^{-\gamma x} + \frac{\beta}{E_x^p \gamma^2} x + cst$$

Transverse response

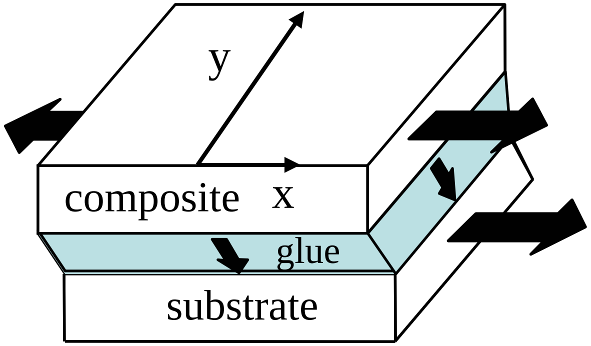


Compression transverse stresses in the patch

Shear stresses in the adhesive



Transverse response



Influence of the difference between Poisson's ratios of patch and substrate

Equilibrium eq. + elasticity ⇒ Transverse stresses:

$$\sigma_{yy}^{p}(y) = K_1' e^{\gamma' y} - \left(\frac{\beta'}{\gamma'^2} + K_1' \right) e^{-\gamma' y} + \frac{\beta'}{\gamma'^2}$$

- Similar to the expression found for the longitudinal response !

- Transfer length in the transverse direction ! $L_{95\%}^{trans.} \approx 3 / \gamma'$

Application to aluminium structure reinforced by carbon/epoxy patch

- with fibres at 0 degree:

⇒ Small difference of Poisson's ratios

⇒ Transverse stresses negligible

- with fibres at 90 degrees:

⇒ Important difference of Poisson's ratios

⇒ High transverse stresses !

Two experimental studies on aluminium specimens:

1) reinforced by a 0 degree carbon/epoxy patch to observe the <u>longitudinal</u> response

2) reinforced by a 90 degree carbon/epoxy patch to observe the <u>transverse</u> response

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Specimens for tensile tests

- Samples reinforced on the two sides (no bending effect)

- Substrate made of Al2024-T3 (4 mm)

- Adhesive Redux 312 (≈ 0.27 mm)

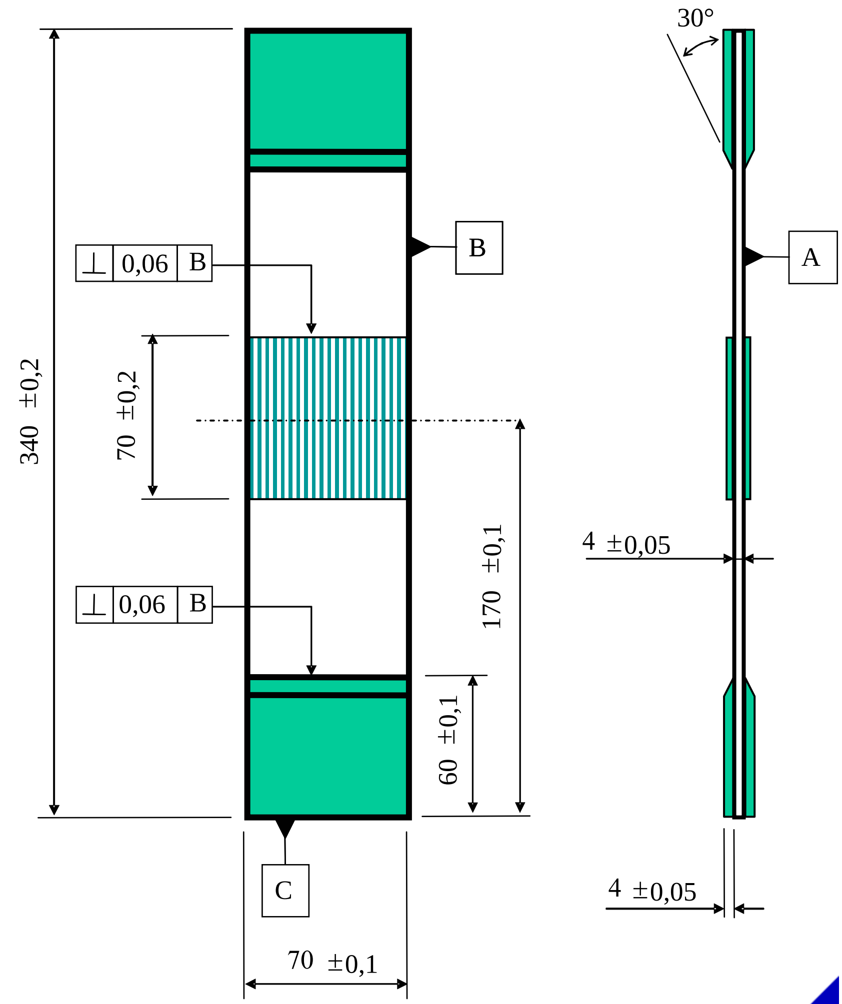
- Patch made of carbon/epoxy (0.5 mm) with 4 plies

1) 0° orientation ⇒ $L^{long.}_{95\%} \approx 8.4$ mm

$L^{trans.}_{95\%} \approx 2.7$ mm

2) 90° orientation ⇒ $L^{long.}_{95\%} \approx 2.7$ mm

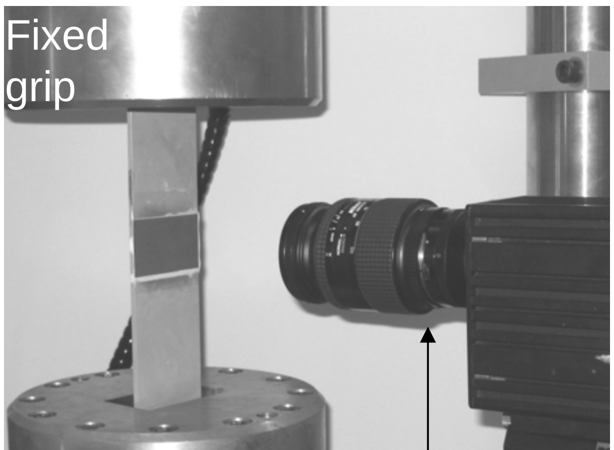
$L^{trans.}_{95\%} \approx 8.4$ mm



Equipments

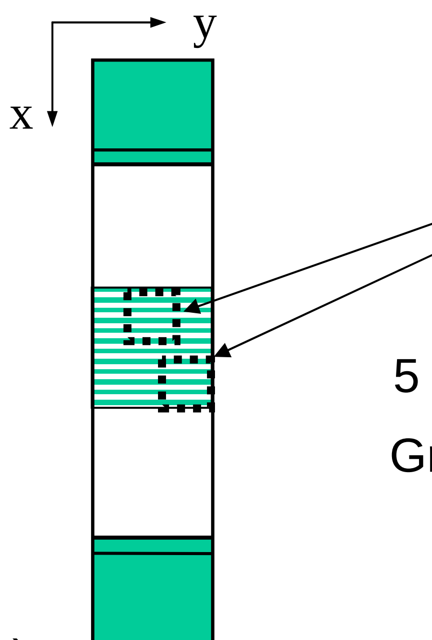
Measurement of displacement fields using the grid method and Frangyne software

[Surrel,94]



Digital camera
1024 × 1024 pixels

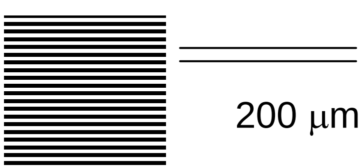
Three tests are performed for each specimen



Observed areas
≈ 40 × 40 mm²

5 pixels between two lines

Grid pitch = 200 μm



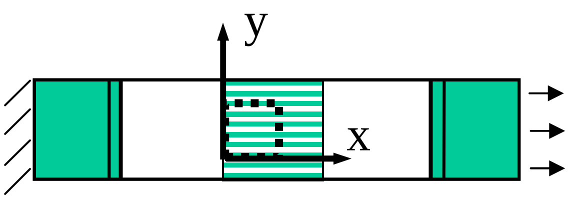
→ pixel 40 × 40 μm²

Spatial resolution: 360 μm (2N-1 algorithm)

Resolution: 1 μm (p/200 with p=200μm)

Processing

For the longitudinal displacements:



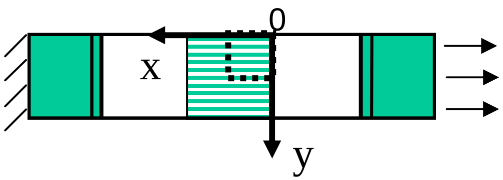
For each column *y = cst* of the image:

the displacement distribution u_x is smoothed using a function similar to the 1D theoretical expression:

$$u_{x\ smooth}^{p}(x) = \frac{1}{C} A e^{Cx} + \frac{1}{C}(B + A) e^{-Cx} + Bx + D$$

Coefficients *A*, *B*, *C* and *D* are optimized for each column by mean squares

For the transverse displacements:



Same processing applied to each line *x = cst* of the image

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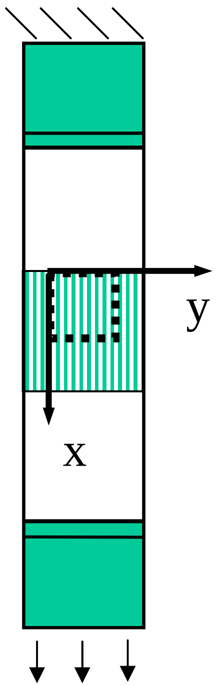
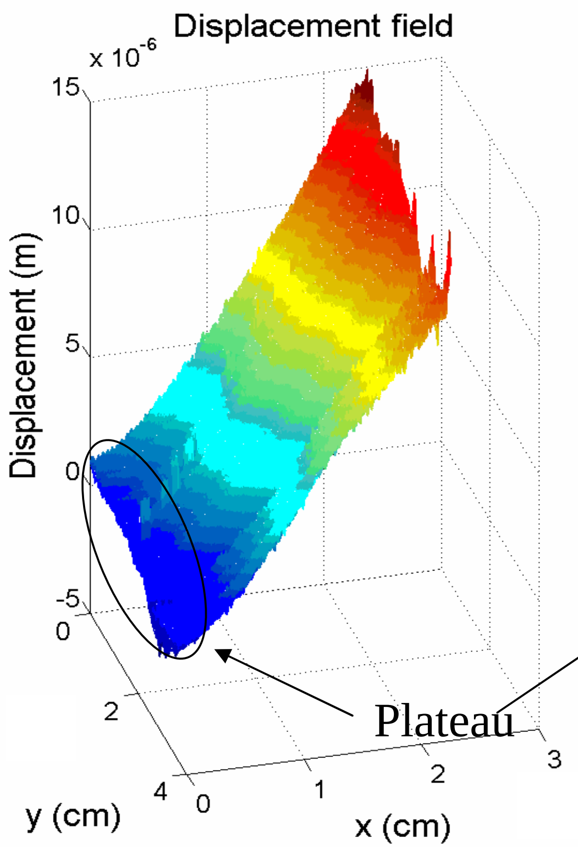
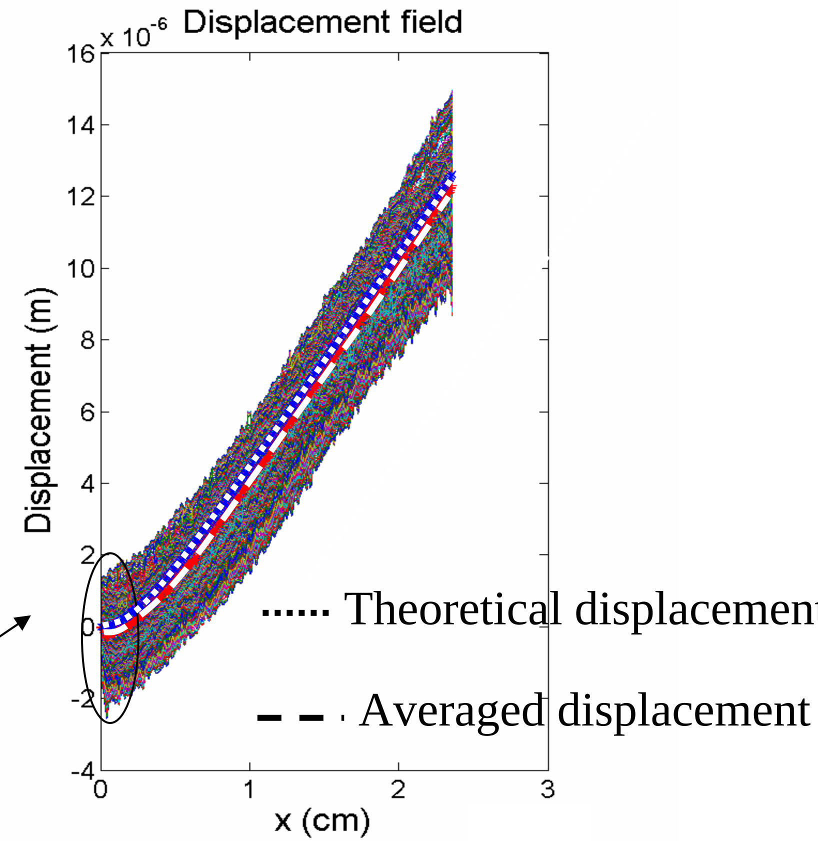
Patch with 0° fibres

Longitudinal displacements

Slippage = 0.13 mm



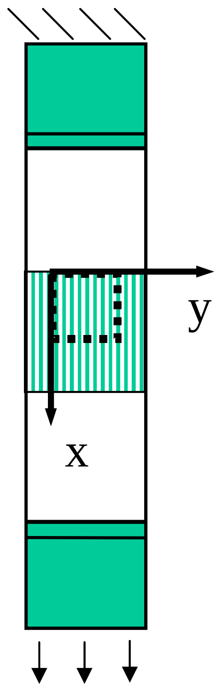


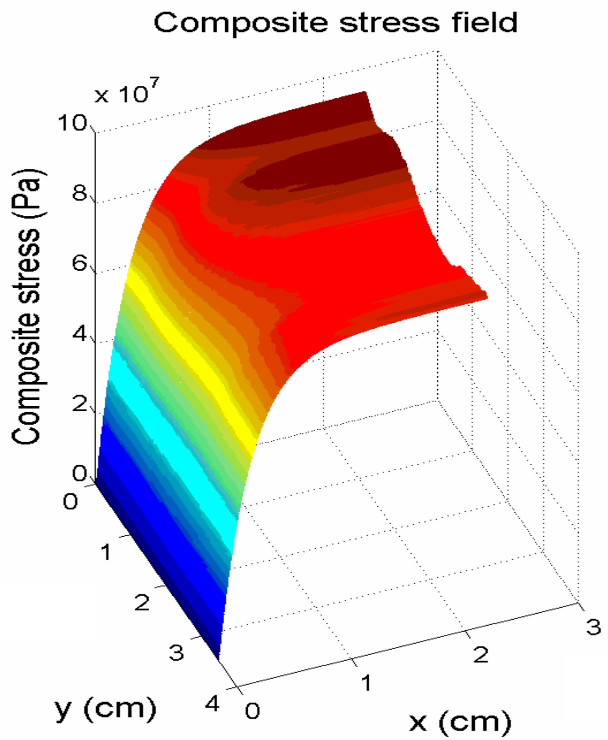


a) Bidirectional view

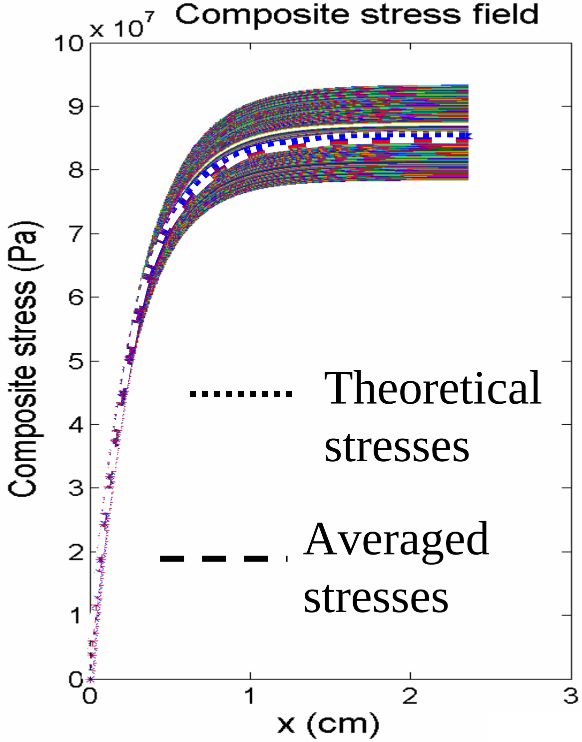
b) Side view

Longitudinal stresses in the composite (patch with 0 degree fibres)





a) Bidirectional view



b) Side view

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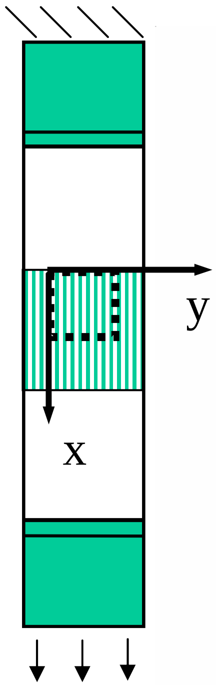
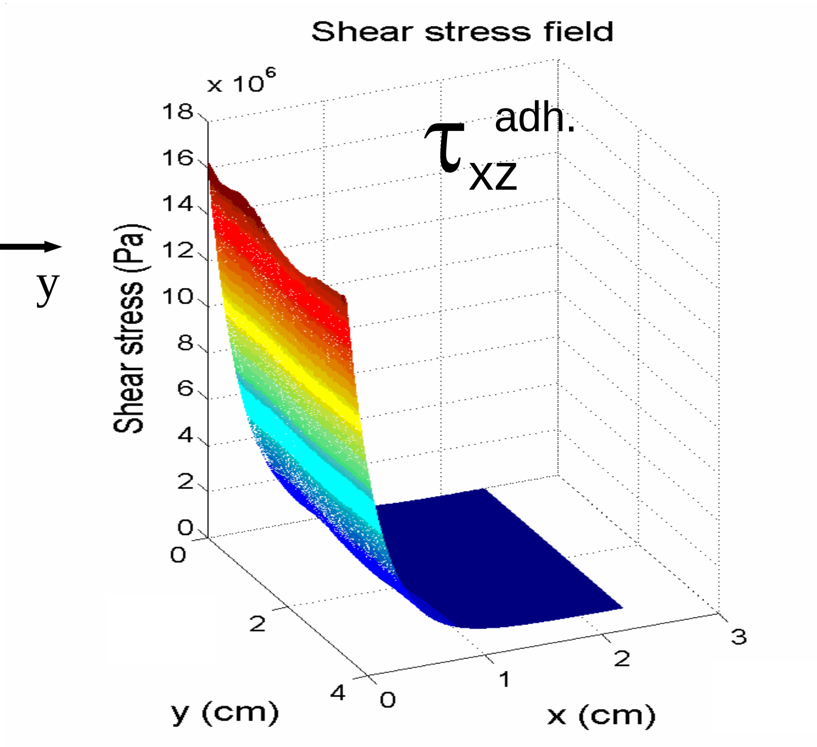
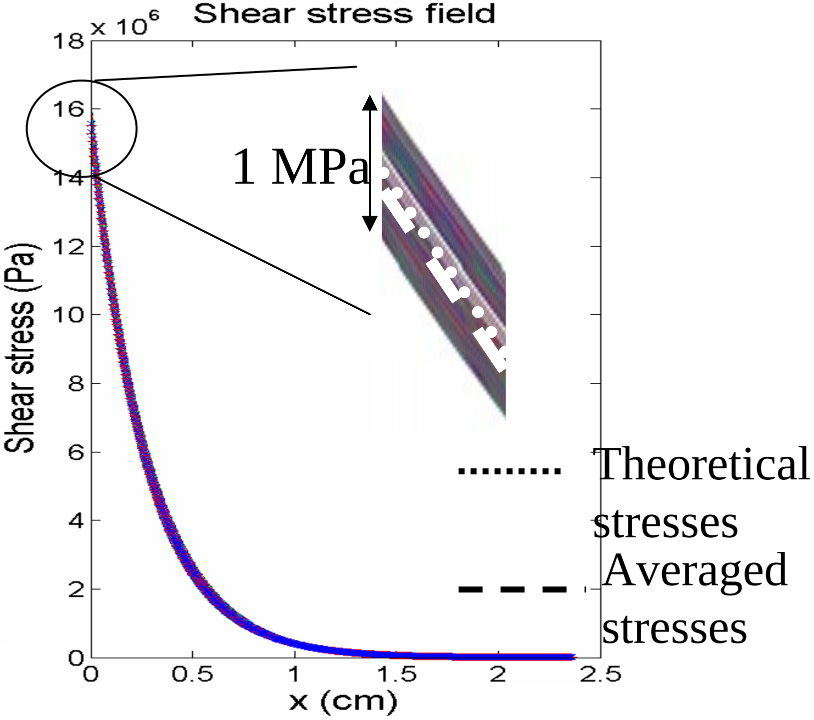
Shear stresses in the adhesive (patch with 0 degree fibres)





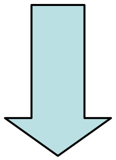
a) Bidirectional view



b) Side view

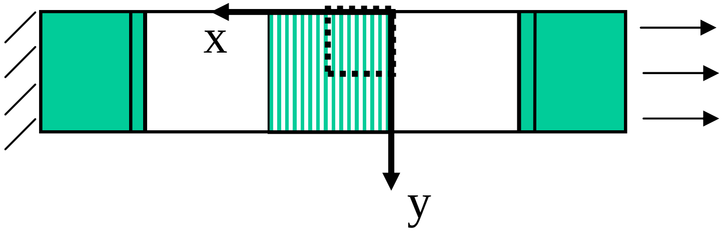
Conclusion for the patch with 0° fibres

- Load transfer clearly observed
- Shear stress concentration in the adhesive correctly measured
- Longitudinal reinforcement correctly described by the 1D approach



Poisson's ratio influence ?

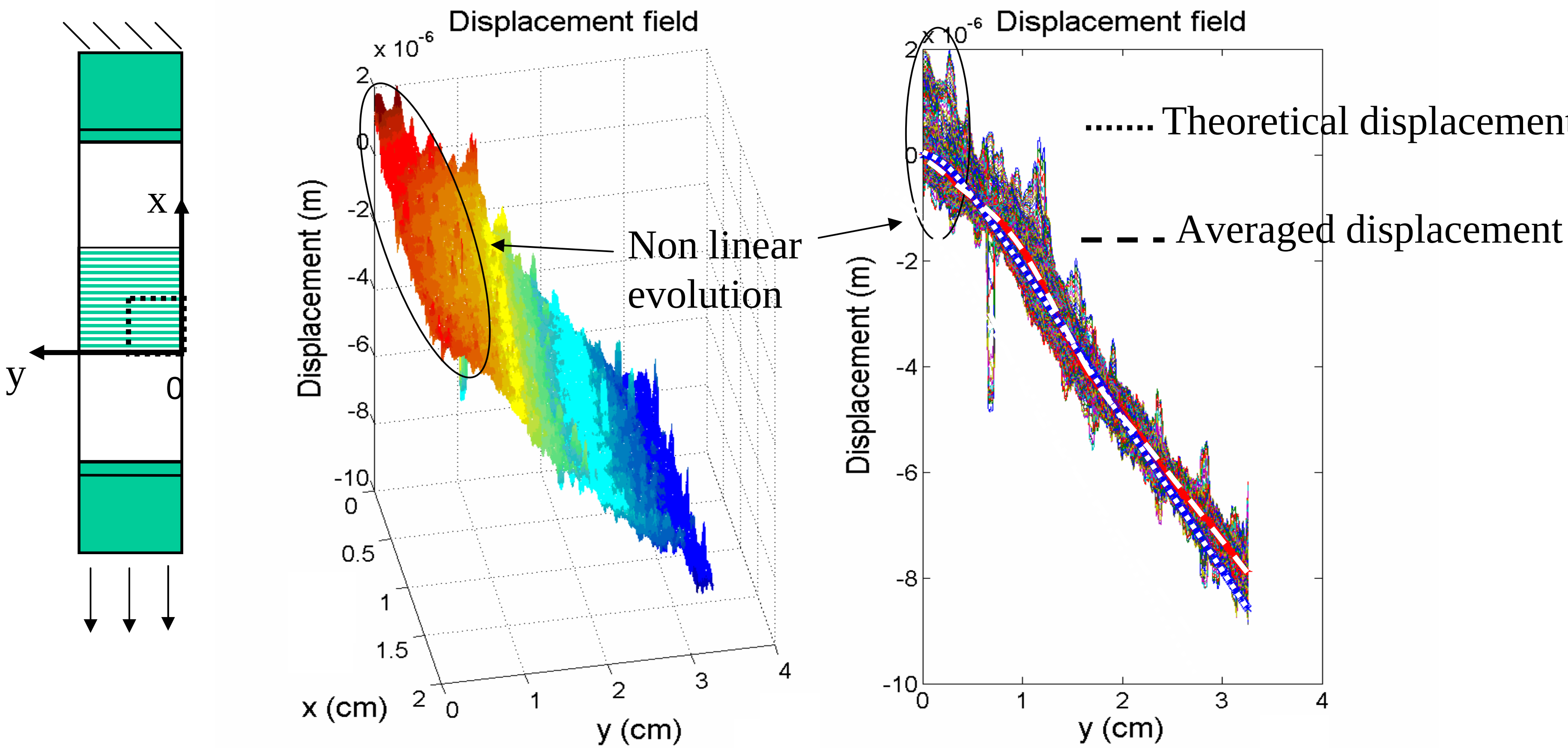
Tests on a patch with 90° fibres



Experimental assessment of transverse components

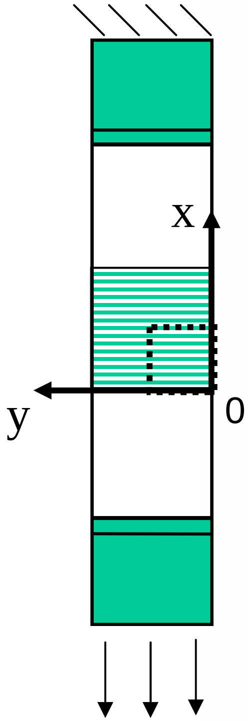
Transverse displacement field (patch with 90 degree fibres)

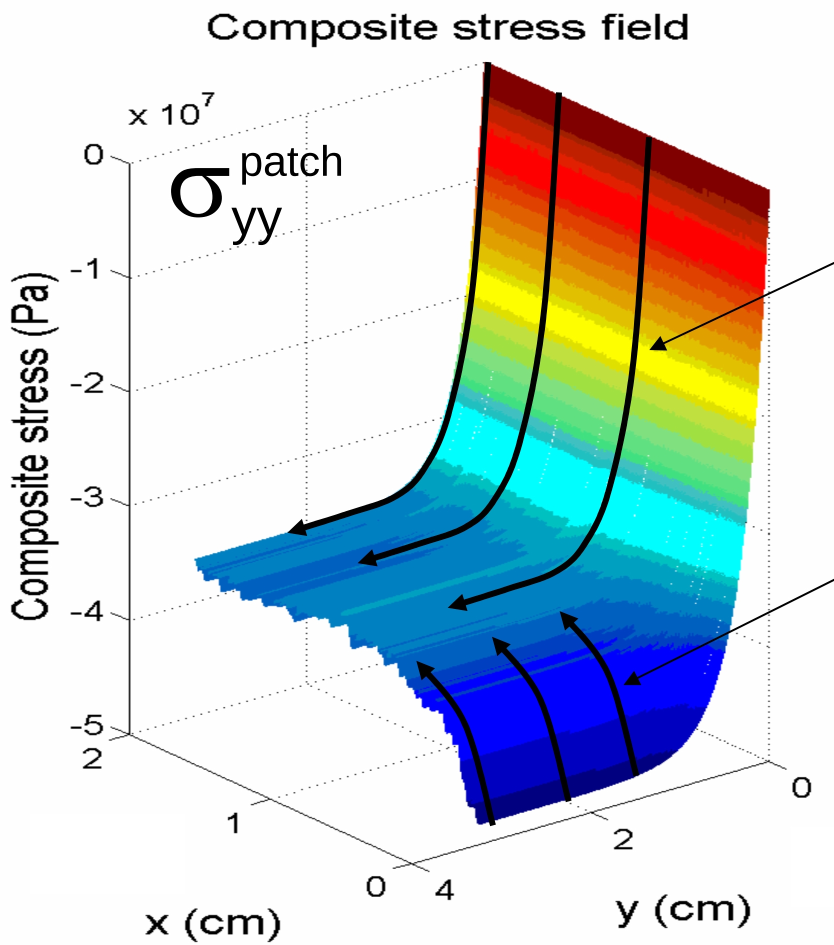
Slippage = 0.11 mm



a) Bidirectional view *b) Side view*

Transverse composite stress field (patch with 90 degree fibres)





First load transfer

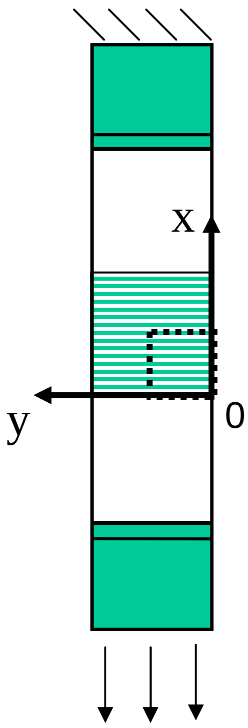
transverse load transfer owing to the difference of Poisson's ratios

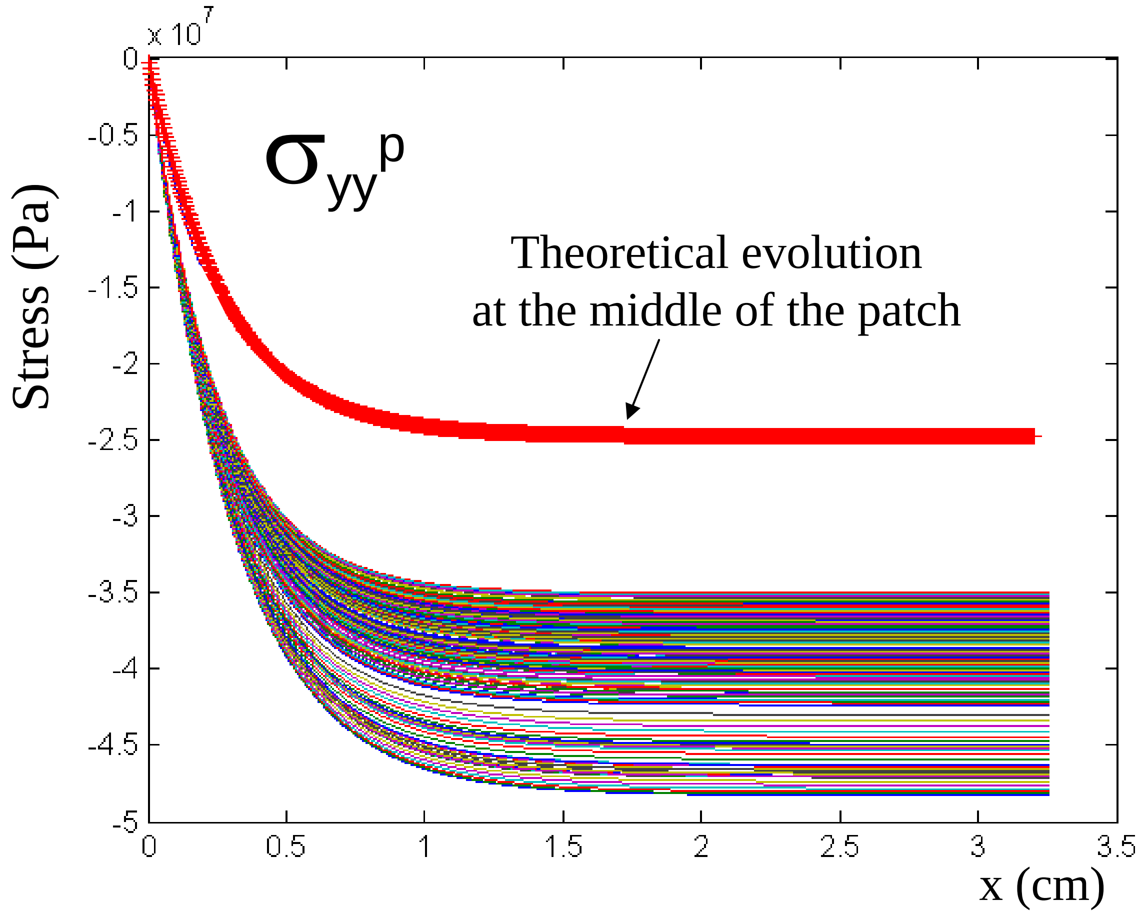
Second load transfer

Stress variation due to:

- difference of Poisson's ratios
- neighbourhood of the free edge (0, x)

Transverse composite stress field   Case of a 90° carbon/epoxy patch

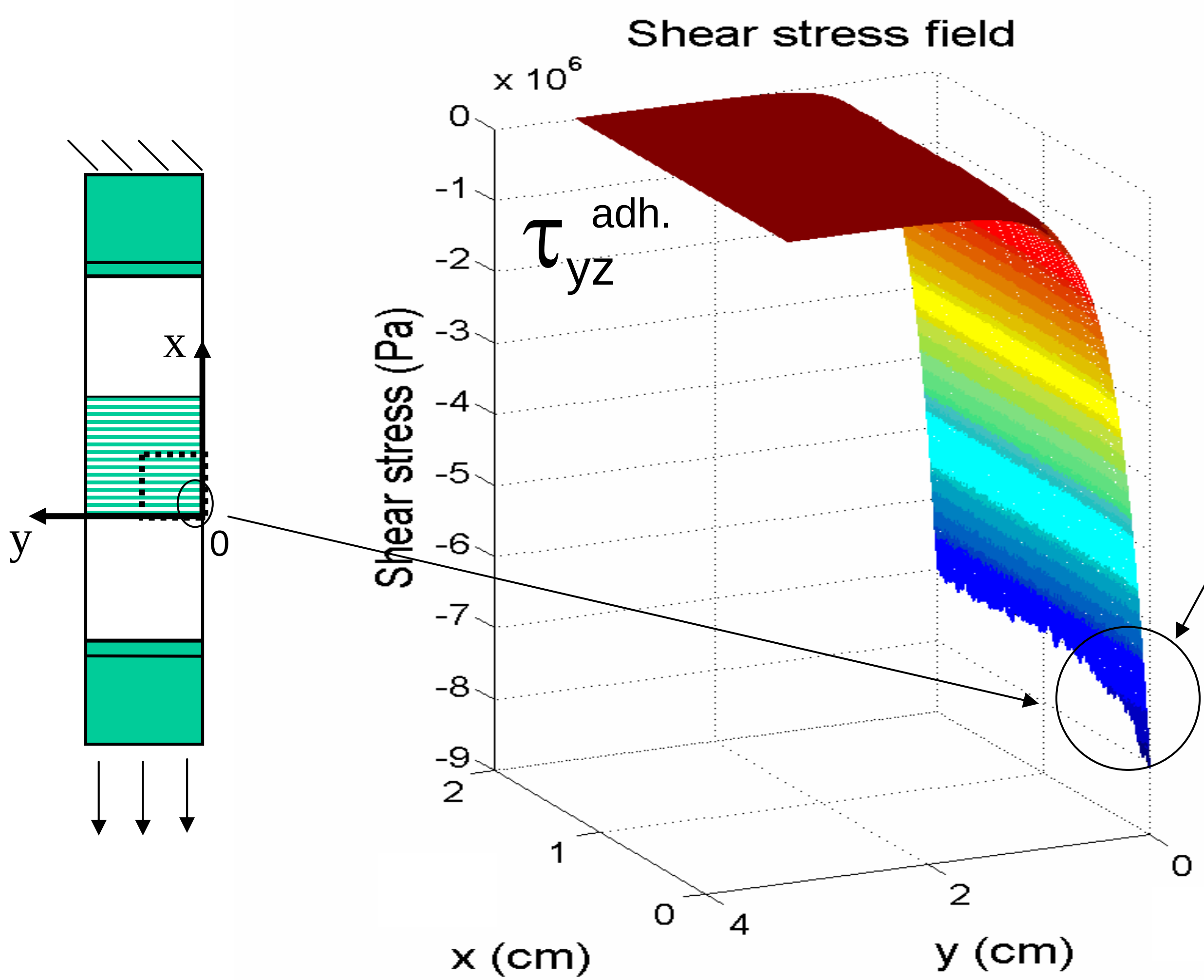




Side view

Transverse adhesive stress field

(patch with 90 degree fibres)



Shear peak owing to the second coupling

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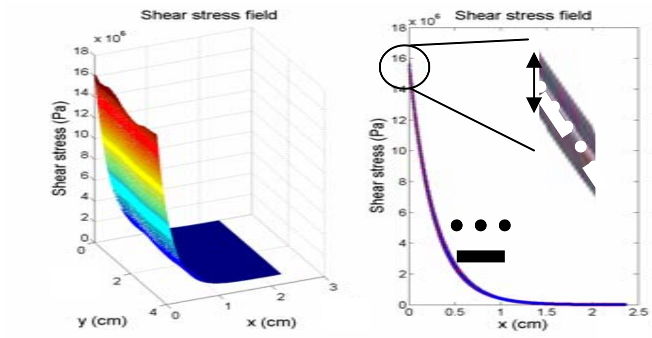
Conclusion:

- Two applications are examined:

  - **Case of a 0° carbon/epoxy patch:**

    Shear stress peak in the adhesive obtained thanks to the grid method

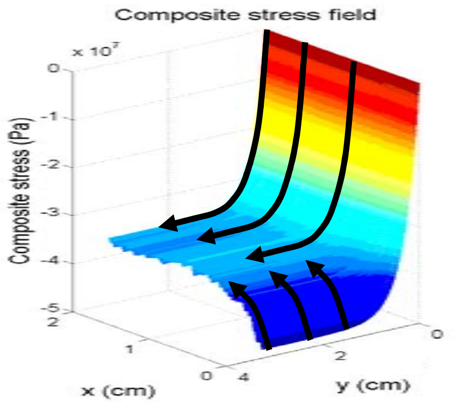
    Longitudinal stress distribution correctly modelled by a 1D theory



  - **Case of a 90° carbon/epoxy patch:**

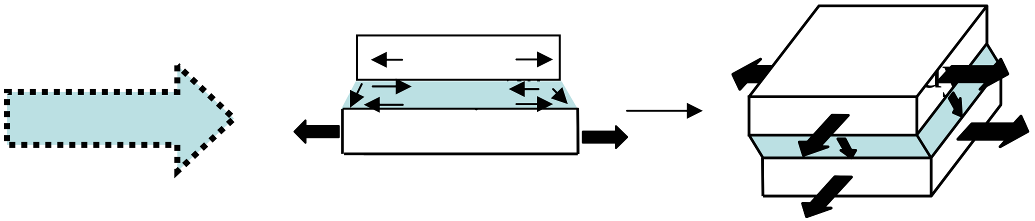
    Significative effect of the Poisson's ratios

    Appearance of a biaxial phenomenon near the free edges, non observed through a 1D modelling



In progress:

Extension of the 1D models to a complete bidimensional approach



Application of the grid method to patches with any shape