University of BRISTOL

CompTest 2004

Use of full field strain measurement to model woven ply

Cyril Bordreuil, Christian Hochard, Noël Lahellec, Frédéric Mazerolle

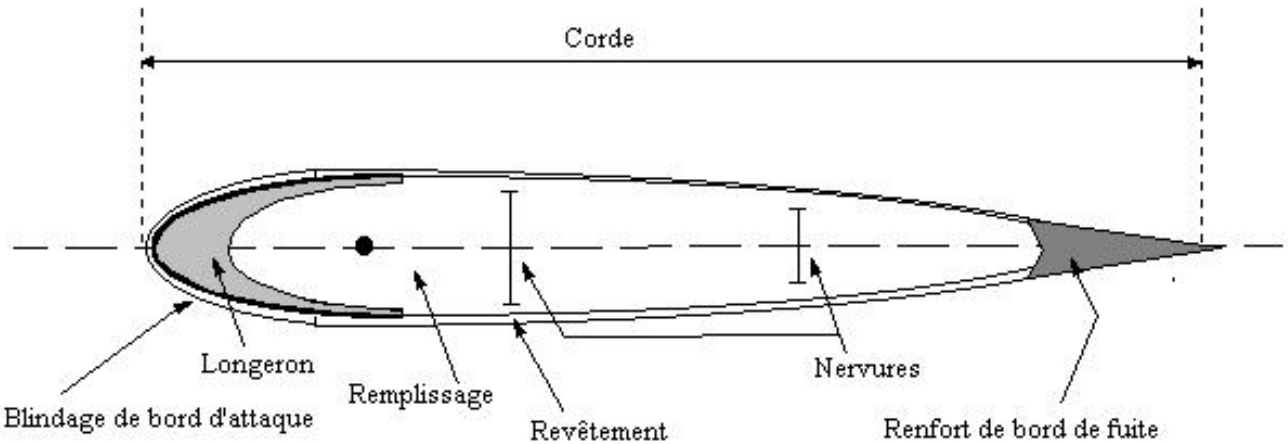
LMA - Laboratoire de Mécanique et d'Acoustique, Marseille, France.

CNRS

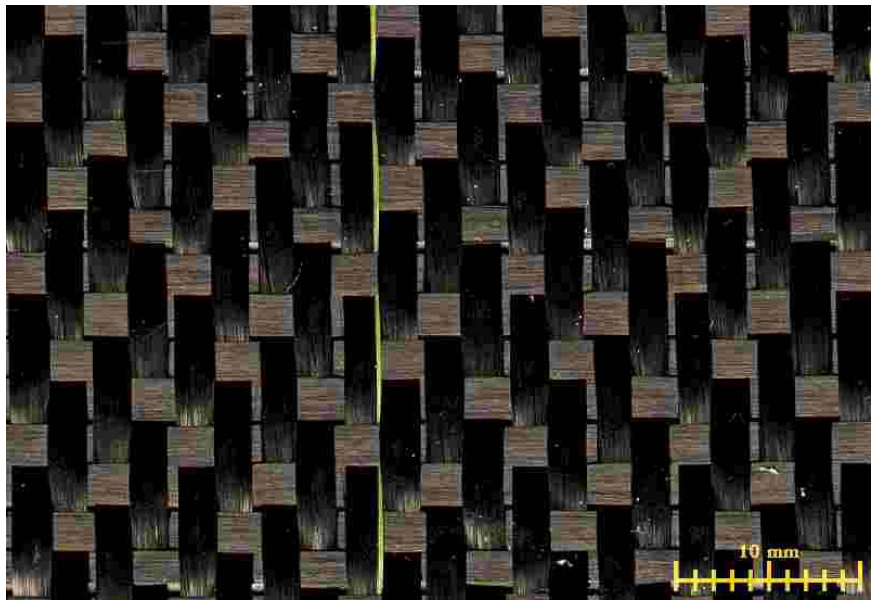
- An application
- The material : Cabon Fiber Woven ply
- Homogeneous Tests
  - Shear
  - Fiber Rupture
- Structural tests : A plate with an open Hole
  - Shear dominant loading
- Fiber rupture and stress distribution
- Continuum damage and Fatigue
- Conclusions

Application Helicopter blade skin

Purpose Prediction of the instant of rupture based on Experiments + Finite element computation



The Material: Carbon Woven ply

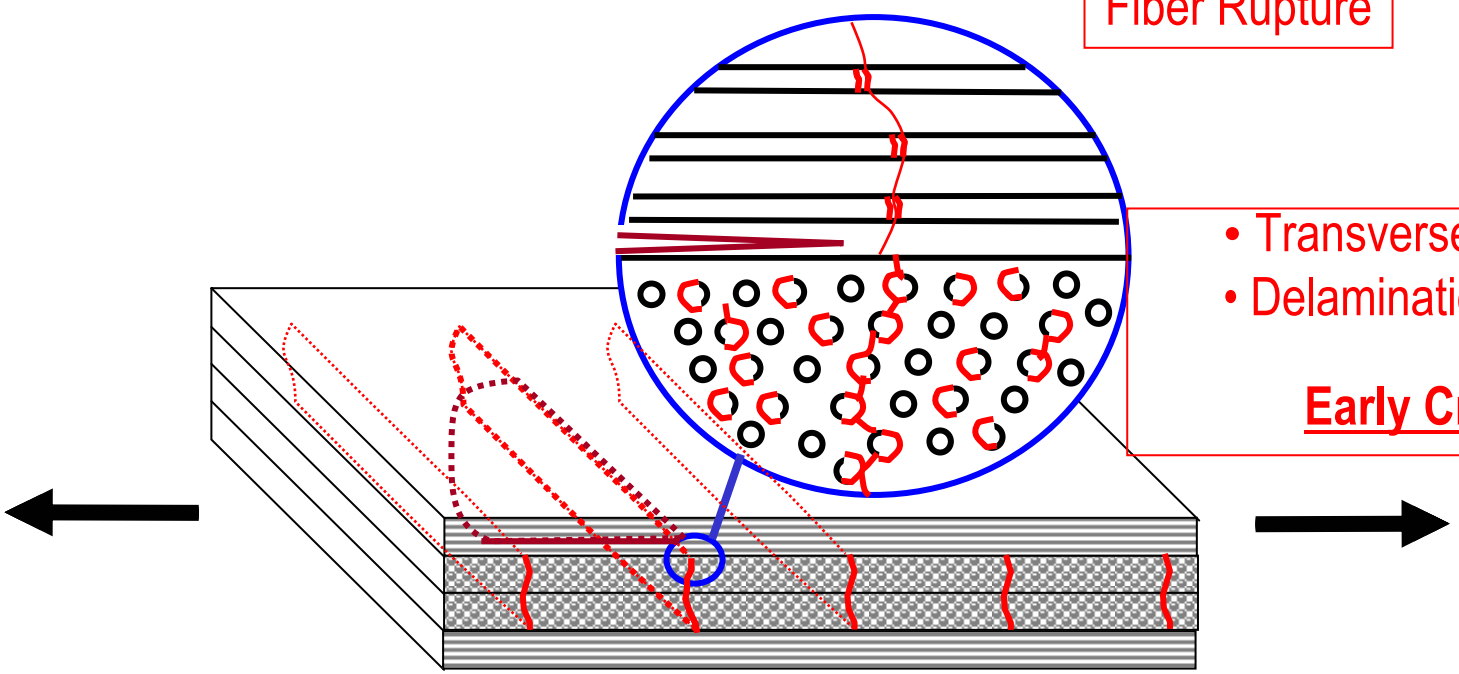


Different phenomenas :

Plasticity And Damage in shear

Damage in composite (UD ply)?

Fiber Rupture



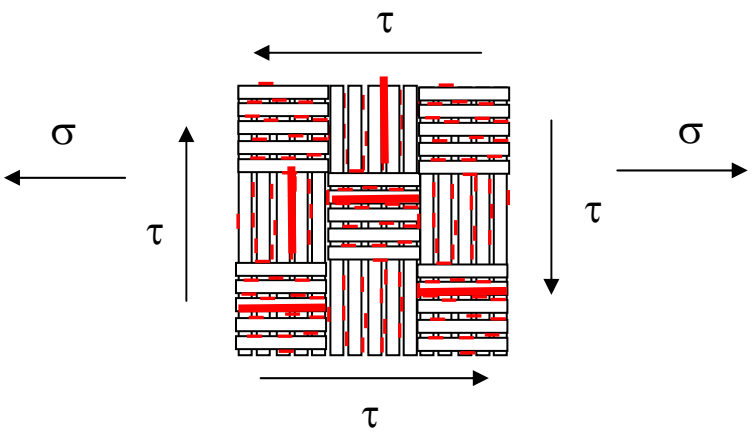
- Transverse Rupture
- Delamination

Early Cracks

- Fibre/matrix debonding
- Matrix cracking

Diffuse Damage

Damage in Woven ply ?



Early transverse cracks are stopped

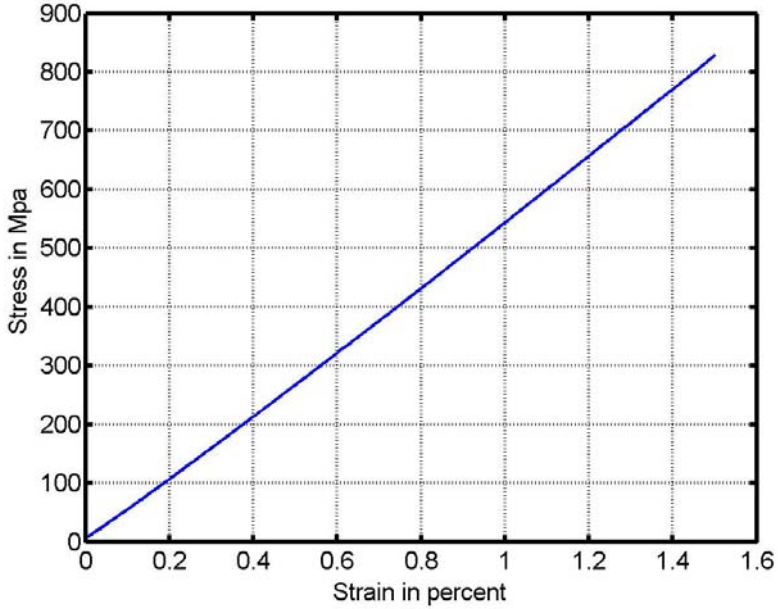
Good resistance to delamination

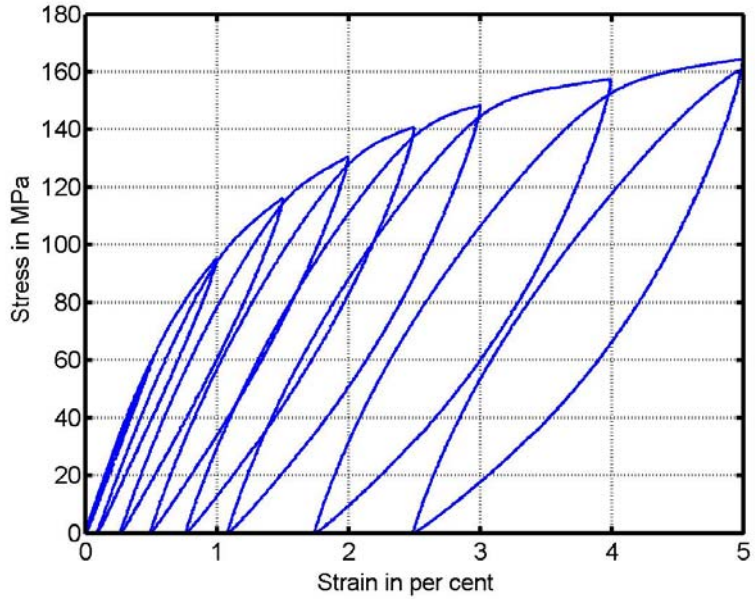
Energie Release rate (J/m2)

Type de pli	G_{CI} (DCB)	G_{CII} (ENF)	G_{mixed} (MMF)
UD Ply (T300/914)	180	440	237
Woven Ply (G802/914)	400	2000	1130

Diffuse damage is dominant=> Model of the ply sufficient

Behaviour in Homogeneous test





- **Fiber direction**
- **Behaviour in shear**

- **Fiber rupture => laminate rupture**
- **Plasticity and damage are coupled**

$$\sigma_i = \sigma_{rupt}$$

Tensile
Shear
Couplings

$$Y = \alpha_1 Y_{d_1} + \alpha_2 Y_{d_2} + Y_{d_{12}}$$

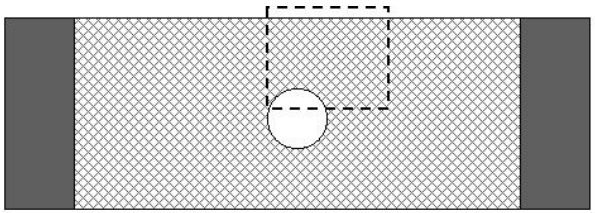
$$\sigma_{12} = G_{12}^0 (1 - d_{12}) \gamma_{12}^e$$

$$f = |\tilde{\sigma}_{12}| - r_0 - Kp^{\gamma}$$

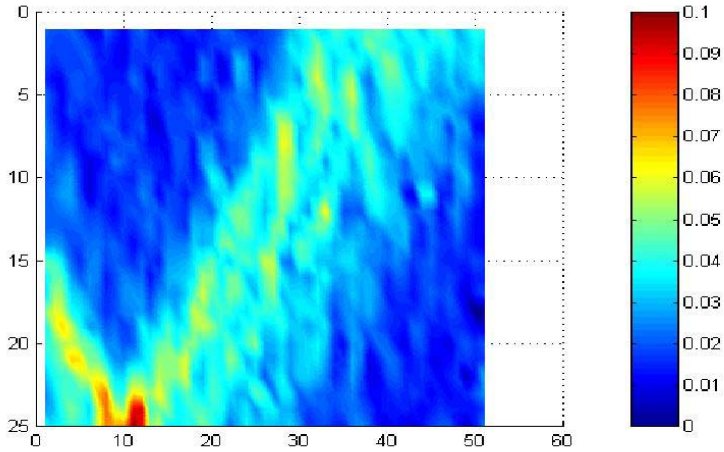
Ladevèze (1992), Hochard et al (2001)

Structural tests: A plate with an open hole

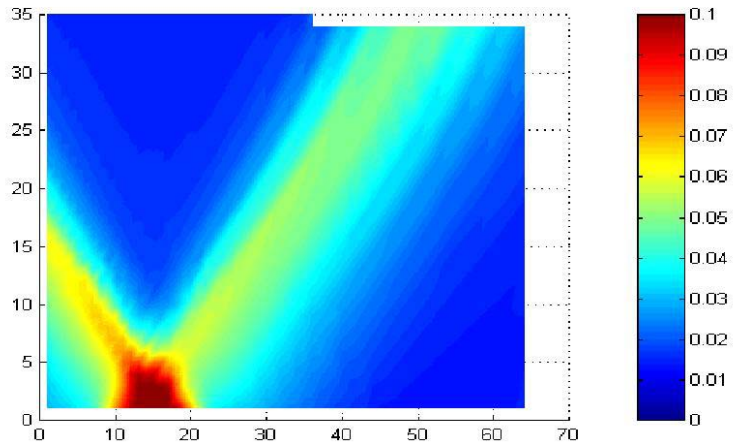
Tests on UD performed by Chang and Chang (1991)



±45 test specimen



Axial strain with Correli (Périé 2002)



FEM (Hochard, 2004)

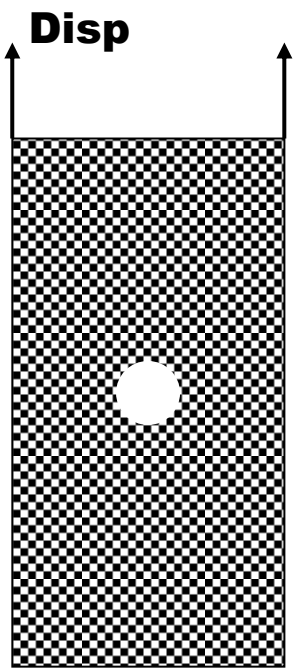
Structural tests: A plate with an open hole

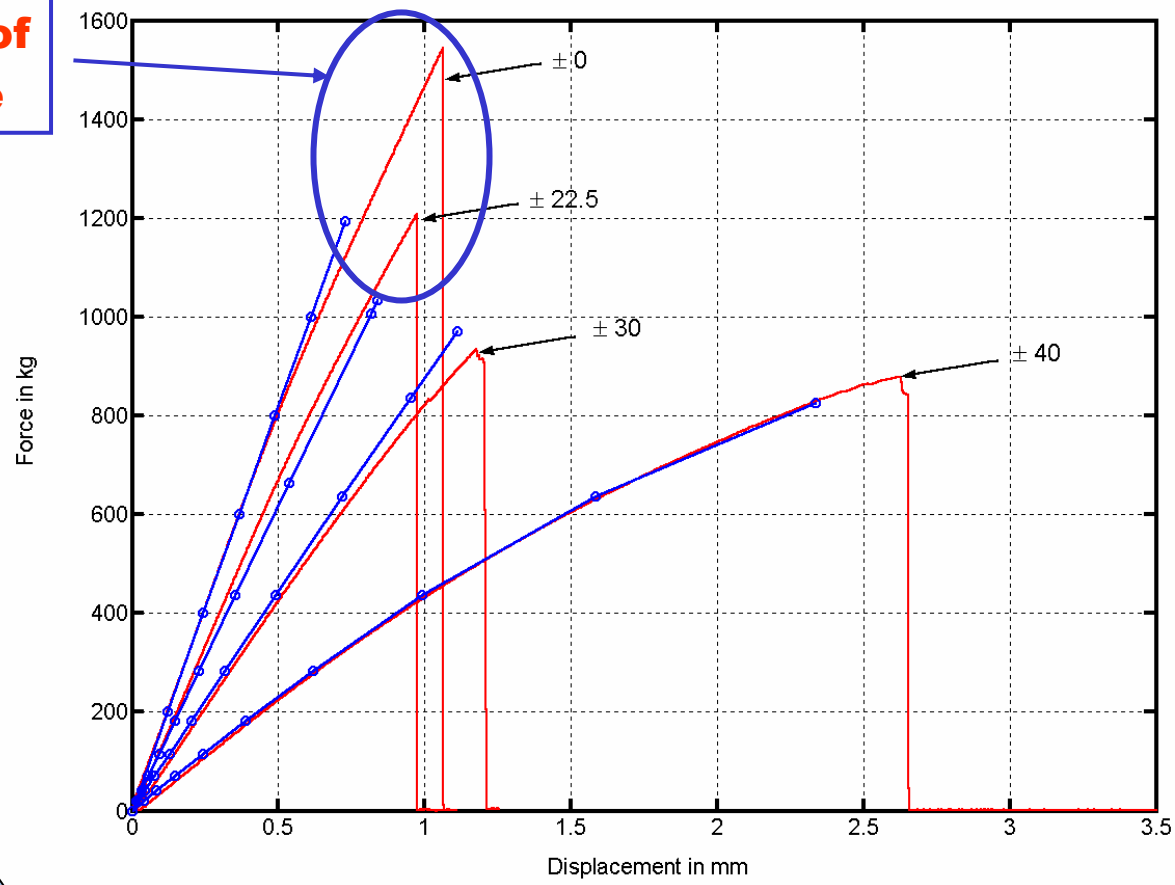
(Bordreuil, 2004)

Computation are stopped when fiber rupture criteria is met. Whole structure ruptured when a cracks appears

Force at rupture

Underestimation of instant of rupture



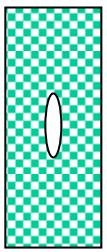


Problem with the local criteria for fiber rupture

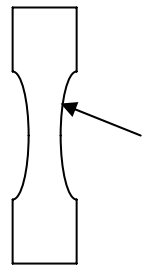
Fiber rupture and stress distributions:

- Local criteria is not representative with stress distributions
- The ply as an in-plane internal length due to the yarn

Use of DIC to catch the strain state in a structure



- Behaviour of the material : Elastic => Quasi isotropic laminate
  - Strains and stresses are simply related
- Structure: Plate with elliptic holes and manufactured specimen
  - Material behaviour with different gradients

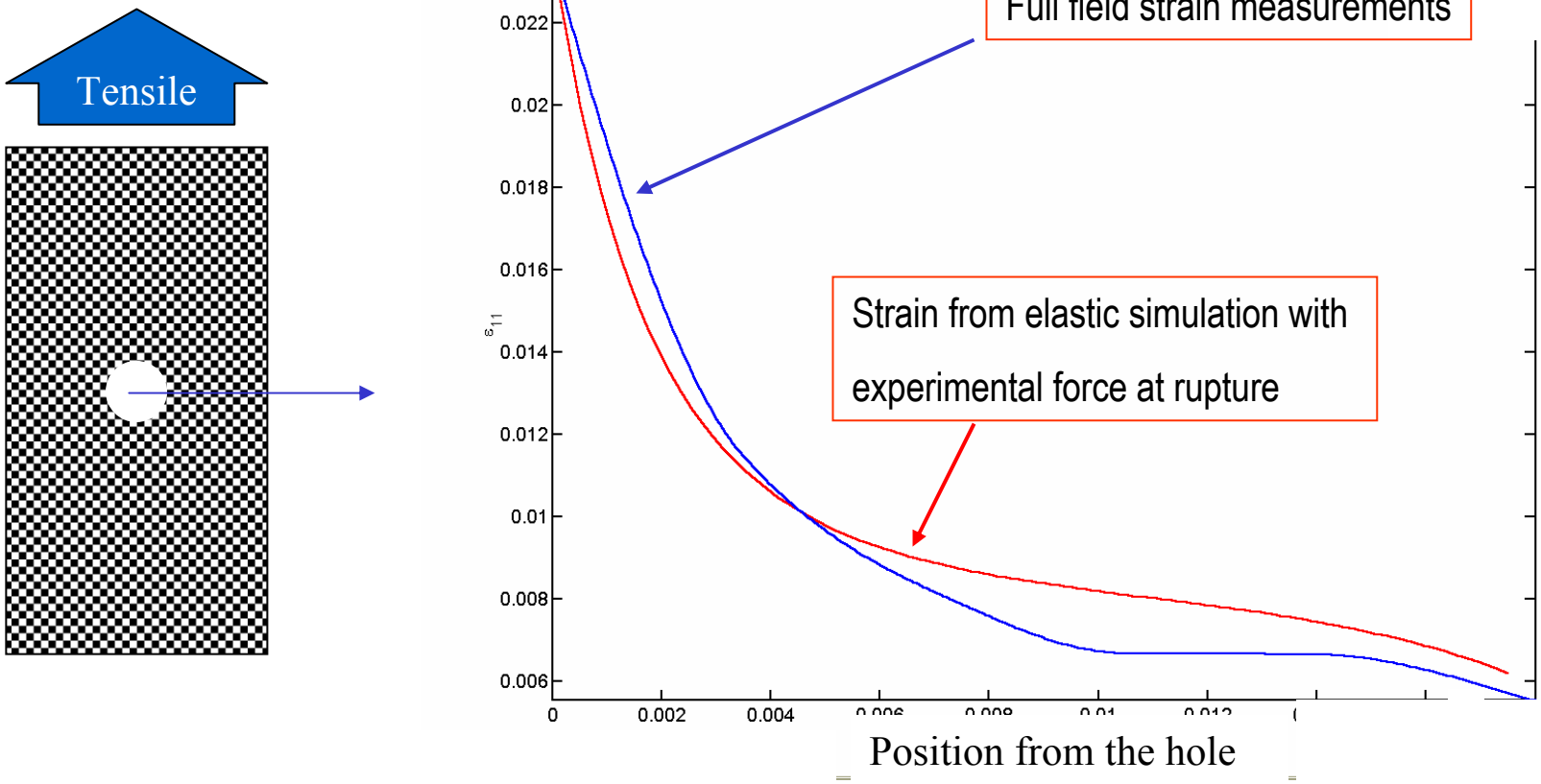


Due to the yarn size => Non local criteria

Withney *et al 1976*, Isupov *et al 1998*, Lahellec *et al 2004*

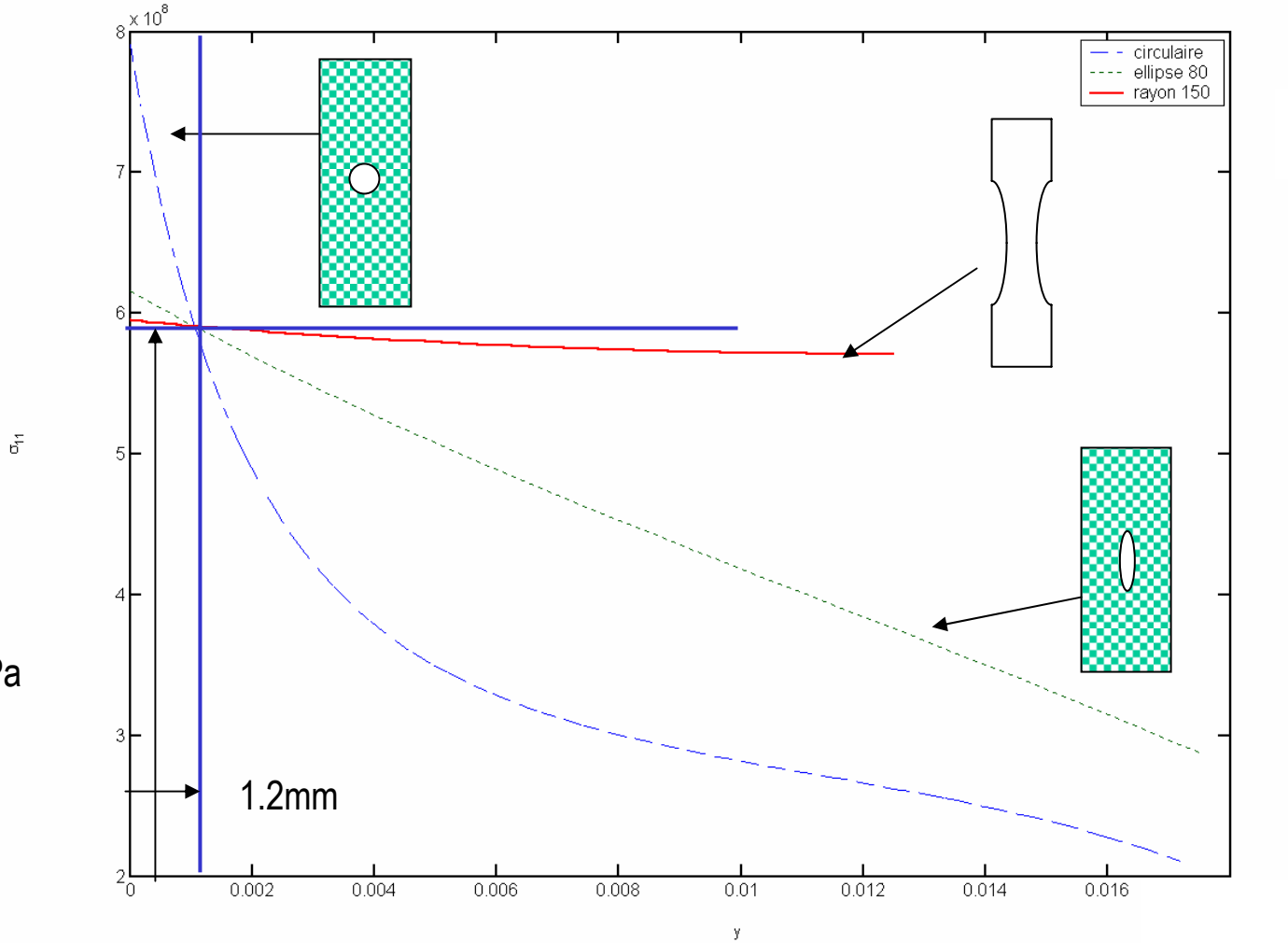
Elastic behaviour before rupture:

Comparison of DIC and FEM strain distributions



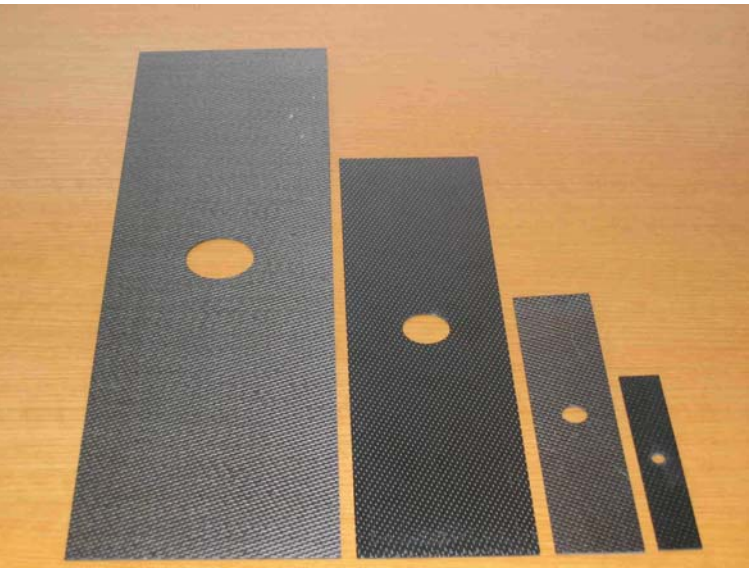
Stress distributions before rupture

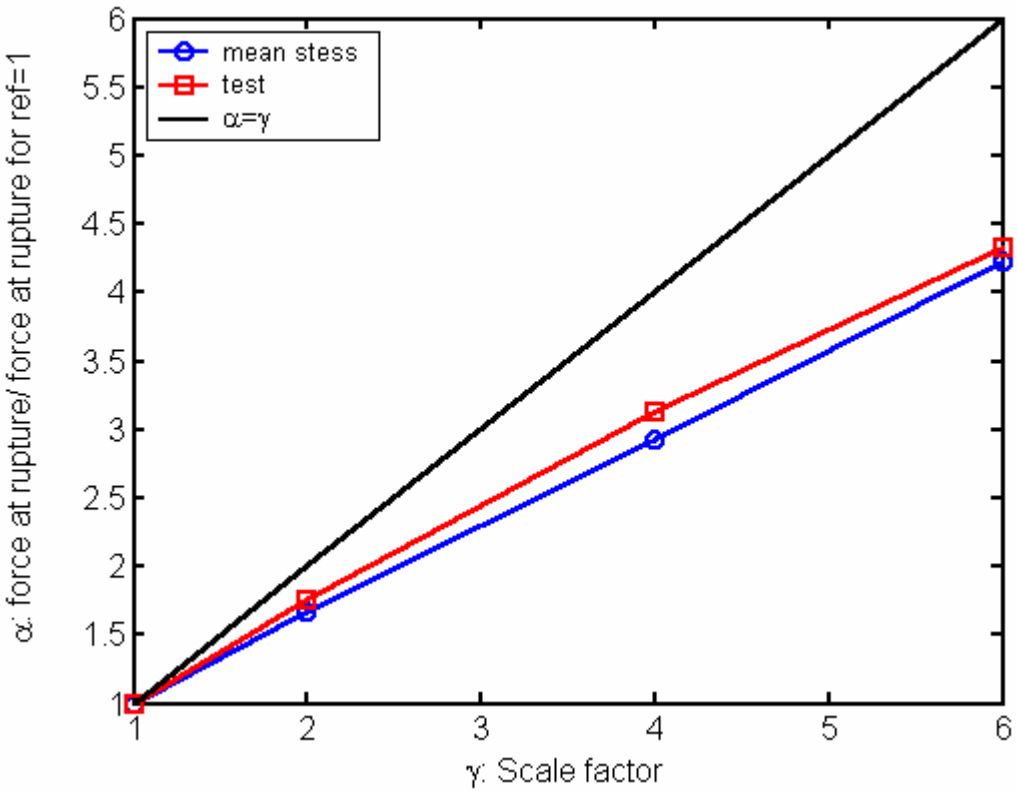
$$\frac{1}{l}\int \sigma_{ii}\, dy = \sigma_{rupt}$$



590MPa

Validation, size effects



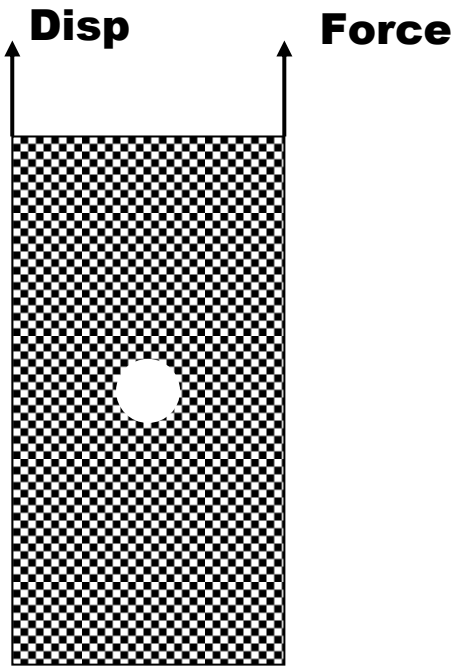


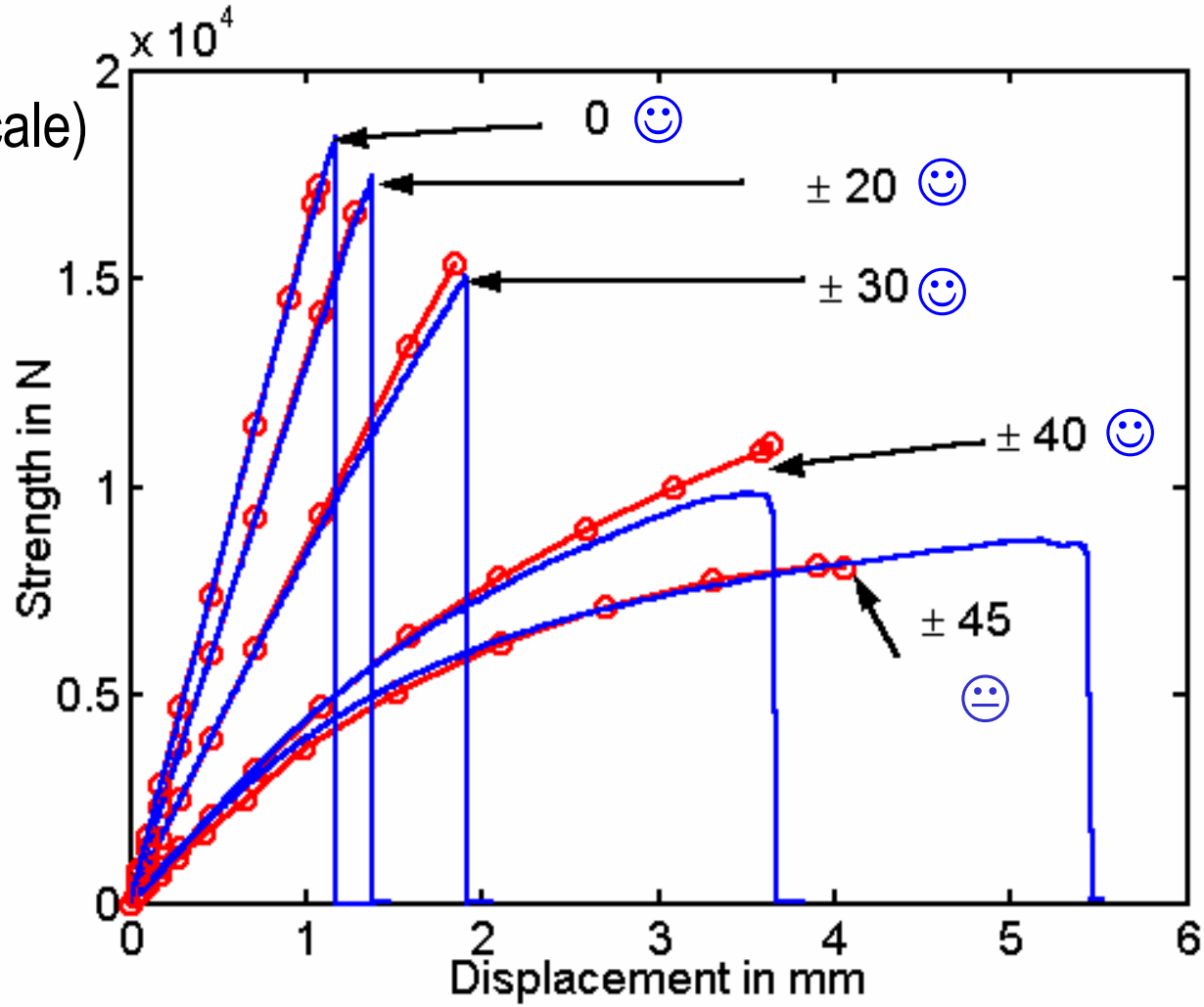
Temporary conclusions:

-Introduction of a non local criteria can take into account size effects for woven ply

Comparison of experiments and computation

Non local criteria in
Fiber direction (ply scale)





Conclusions for static loadings:

- Good prediction of the instant of rupture
- Some works on tensile/shear and compressive/shear couplings

- Abaqus Routines Umat already available (woven ply) and Urdfil soon on request to:

cyril_bordreuil@yahoo.fr, hochard@unimeca.univ-mrs.fr

Continuum damage and Fatigue:

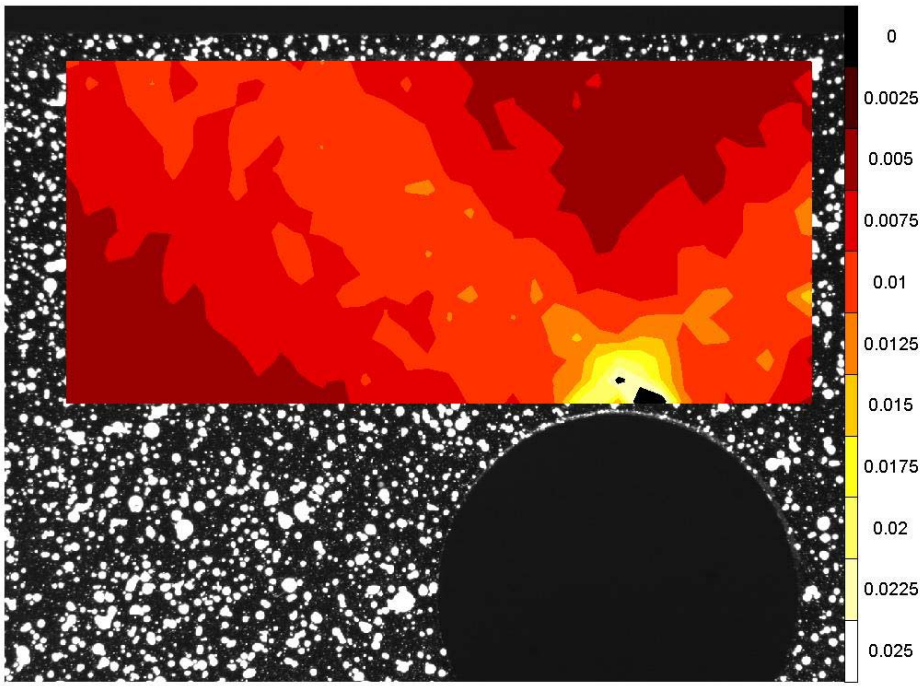
Does Continuum damage representative when a woven ply laminated Structure is submitted to fatigue loading? Does any macro cracks Appears?

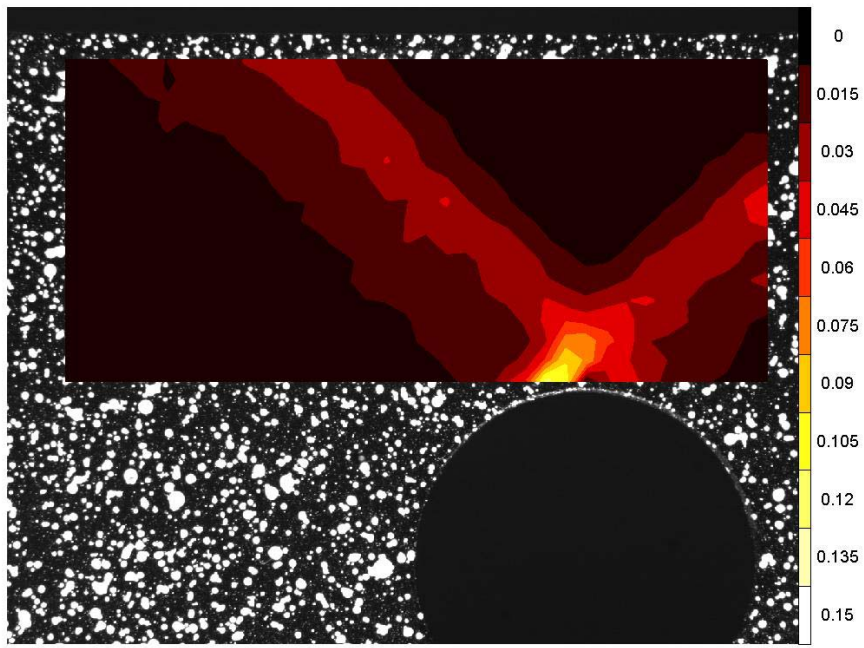
$\Rightarrow$Performed structural tests with fatigue loading and observe together with images if cracks appears and with DIC the evolution of strains.

$$\frac{\partial d_f}{\partial N} = f(Y_{max}, Y_{min})$$

Continuum damage and Fatigue:

No cracks were seen until near rupture





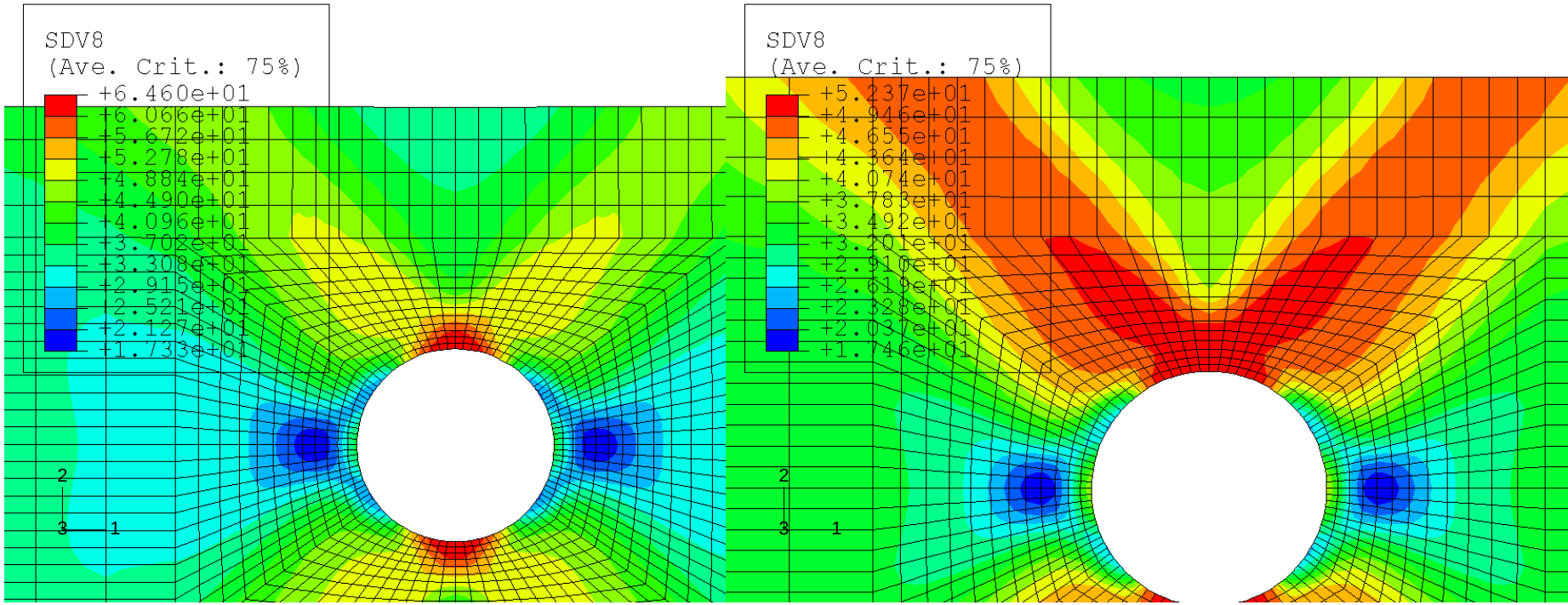
Static loading 550kN

After 30,000 cycles

Strain maps coincide with strain localization seen on the specimen

Continuum damage and Fatigue:

FE Simulation seems to be allowed.



Maximum shear stress map in the structure (axial strain is similar)

Use of full field strain measurements:

-To validate local behaviour in shear
-To validate behaviour of the laminate
-To see strain evolution under fatigue loading

Coupled with FE simulation in order to better predict coupling on plasticity and damage based on an inverse method