Non-homogeneous CFRE strain field monitoring with the electronic speckle pattern interferometry technique

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Outline

Long term mechanical behaviour of unidirectional carbon fibre reinforced epoxy composite system

- creep and creep-recovery behaviour
  - **elasticity, plasticity**
  - **visco-elasticity, visco-plasticity**
- fatigue cycles - creep measurements
  - **damage**
- strain measurement methods
- damage and rupture initiation detection

Material and experimental conditions

Unidirectional Carbon fibre reinforced Epoxy matrix

* prepreg on roll (Hexcel Fiberdux 920 CX-TS-5-42)

Production method: Autoclave cure

* DSC improved temperature cure programme

Rectangular testsample

* L x l x th = 300mm x (approx.) 17mm x 1.5mm
* 10 layers unidirectional stacking

Tensile creep load

* s = constant
* Temperature and moisture = ambient conditions

Non linear viscoelastic, viscoplastic and damage analysis

$$\boxed{e = e_{elastic} + e_{viscoelastic} + e_{viscoplastic} + e_{damage}}$$

uniaxial non linear viscoelastic strain-stress relation (Schapery)

$$e(t) = g_0 S_0 s(t) + g_1 \int_0^y \Delta S(y - y') \frac{d[g_2 s(y')]}{dy'} dy'$$

$$dy' = \frac{dt}{a_s}$$

S_0 instantaneous compliance

ΔS transient compliance

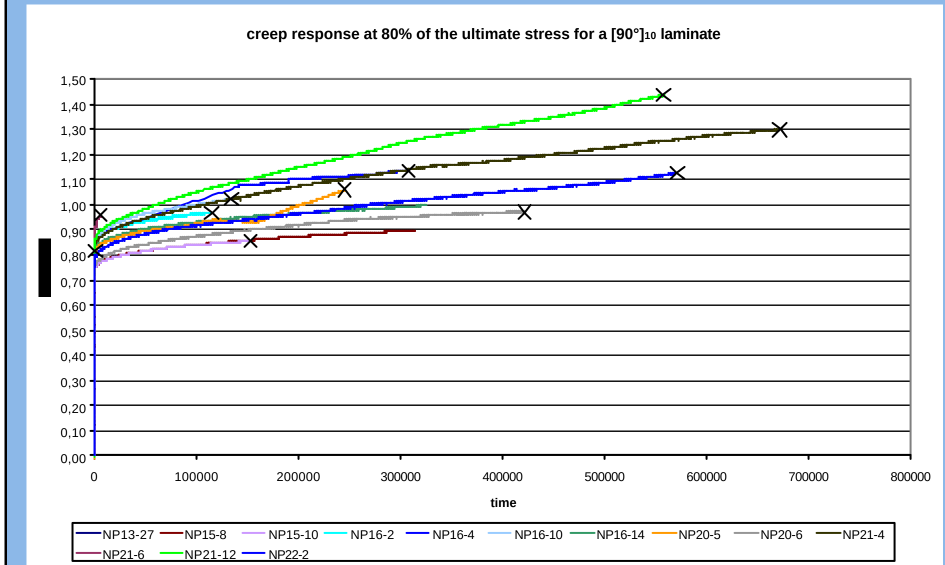
g_0, g_1, g_2 and a_σ are the nonlinearizing functions

uniaxial non linear viscoplastic strain-stress relation

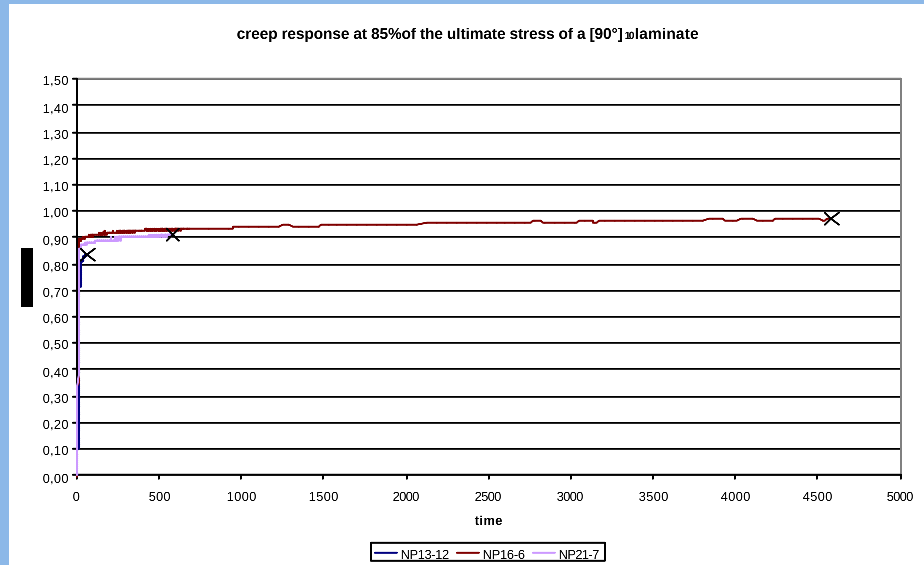
$$e_{VP} = \Phi\{(g_3[s(t)])dt\}$$ Zapas-Crissman functional

Experimental creep strain results $[90]_{10}$ with strain gages

80% ultimate strength



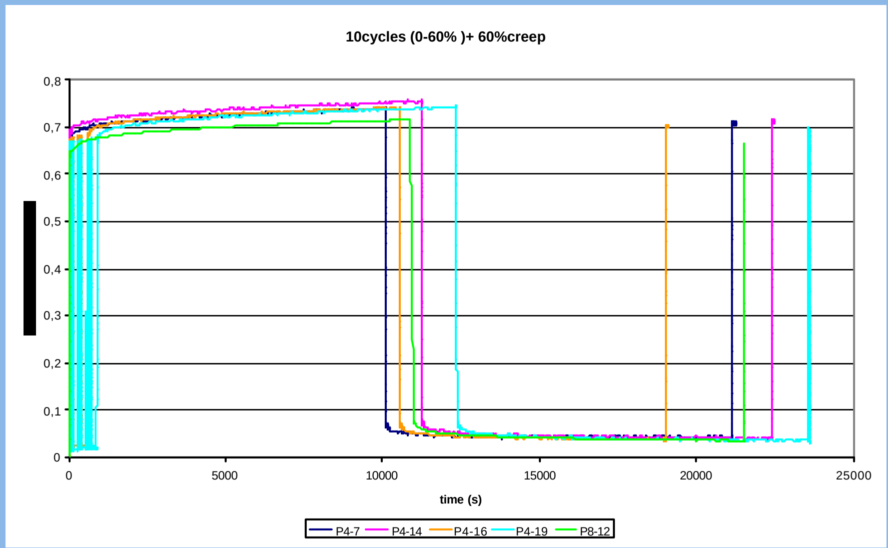
85% ultimate strength

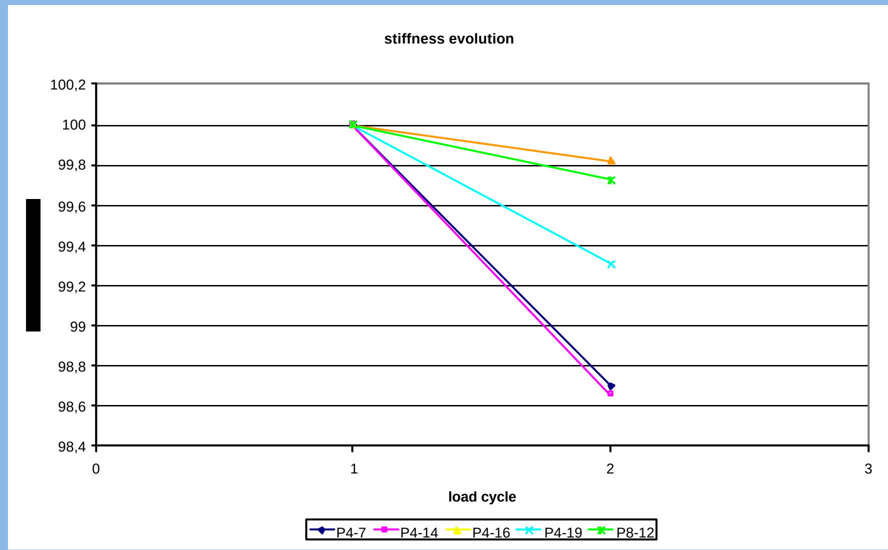


- different strain rates
- different lifetime (rupture X)
- non representative strain response

Damage analysis with strain gages

stiffness response at combined fatigue and creep-recovery cycles

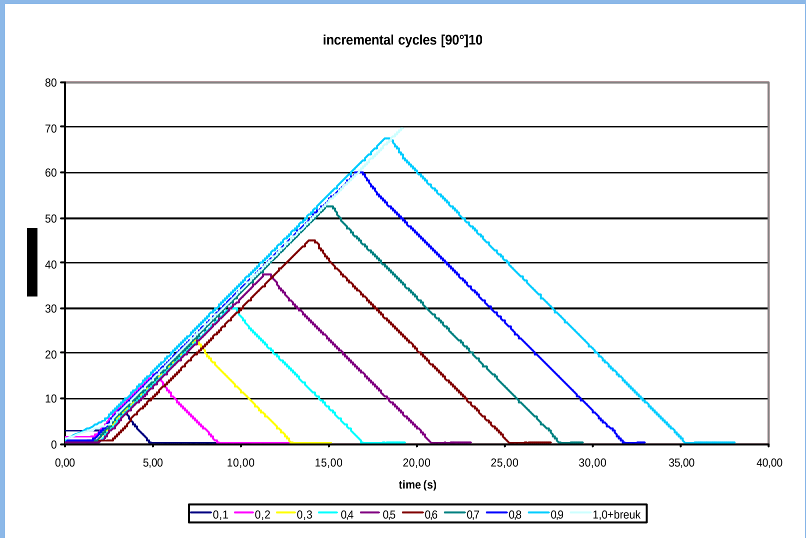


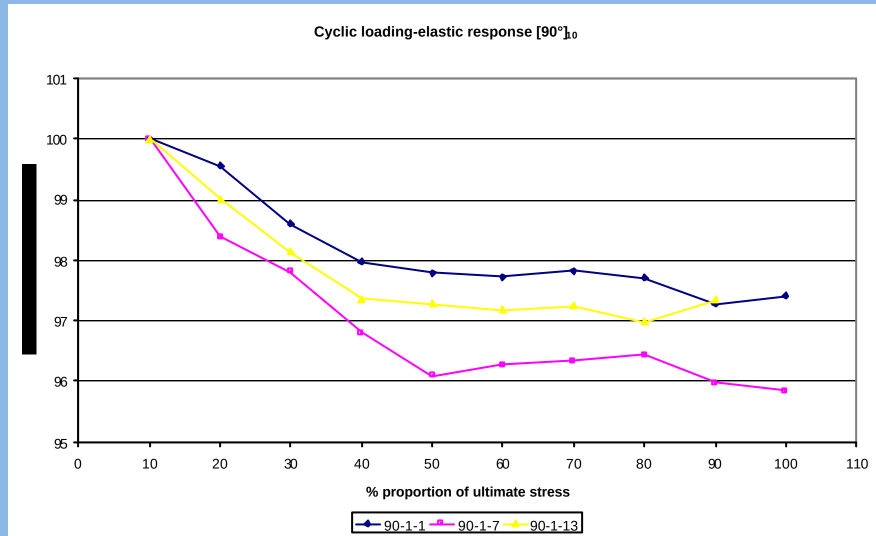


- decreasing tendency
- non-significant response vs. accuracy measurement device

Damage analysis with strain gages (2)

stiffness response at incremental load cycles

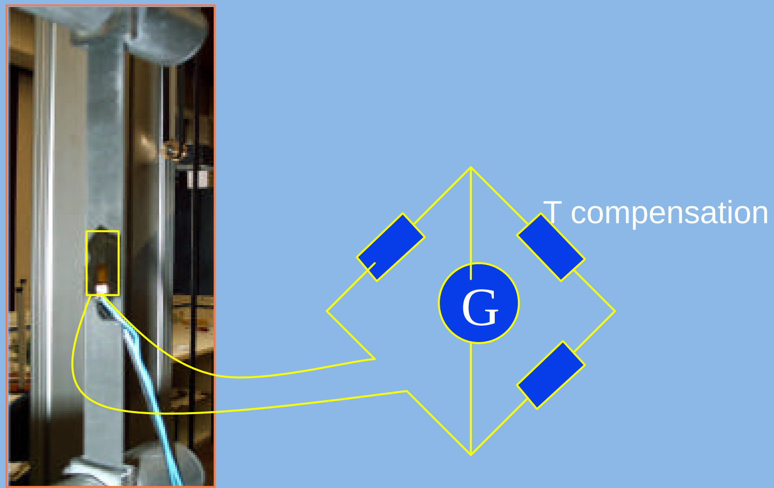




- decreasing tendency
- non linear damage development
- non-significant response vs. accuracy measurement device

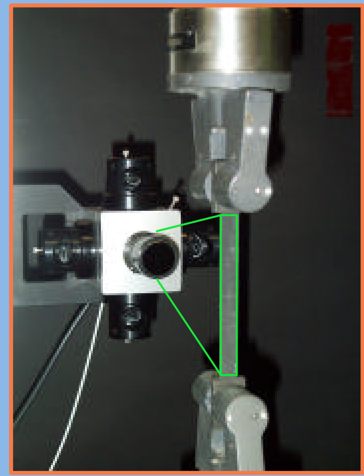
strain measurement techniques survey

electric strain gage / extensometer technology



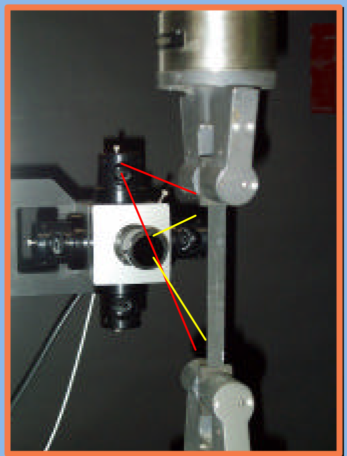
- local measurement
- average result of gage surface
- worked interface method
- sensor alignment sensitivity
- T- compensation (half bridge)

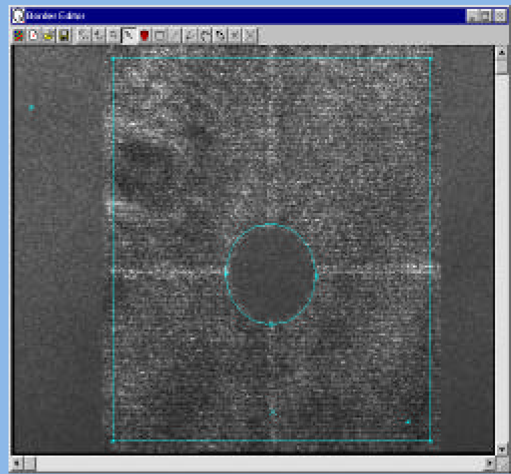
Electronic speckle pattern interferometer



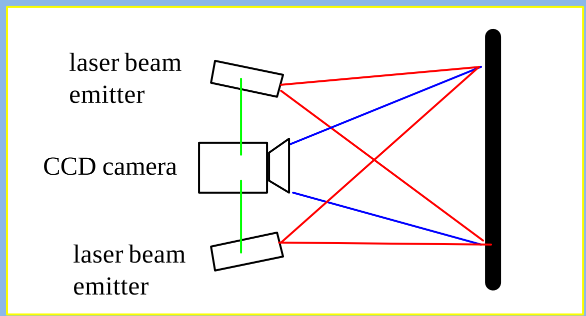
- full field monitoring
- high resolution
- contactless method
- high sensitivity to noise (infrared light, heat source, air flow,vibration)

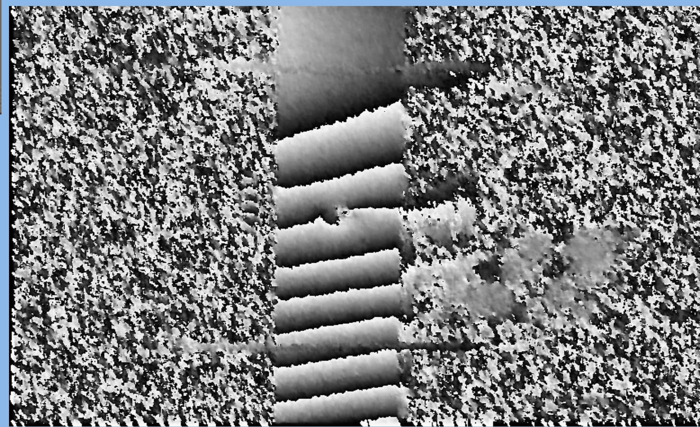
Optical strain measurement technique: Electronic speckle pattern interferometry





live image





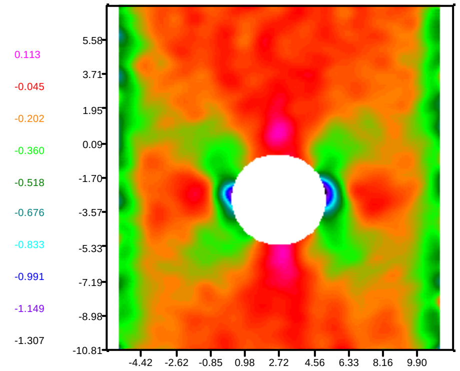
Fringe pattern

- global, digital measuring method
- high resolution and sensitivity

ESPI strain patterns [+/-45°, 90°$_3$]$_s$

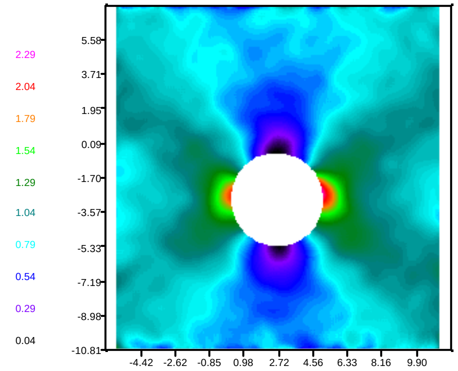
Strain x-direction [µm/mm]

F: 252 N -> 607 N ; 5 Steps

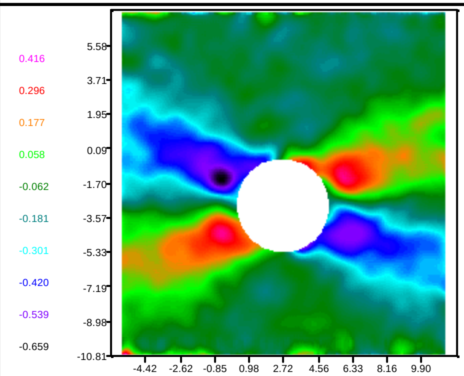


strain y-direction [µm/mm]

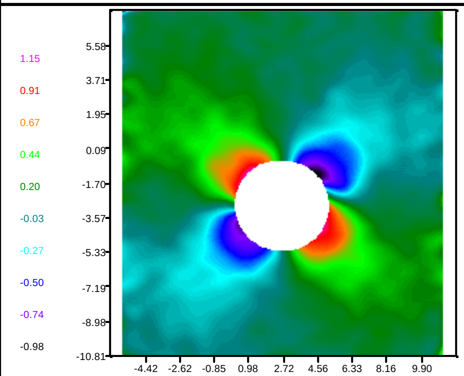
F: 252 N -> 607 N ; 5 Steps



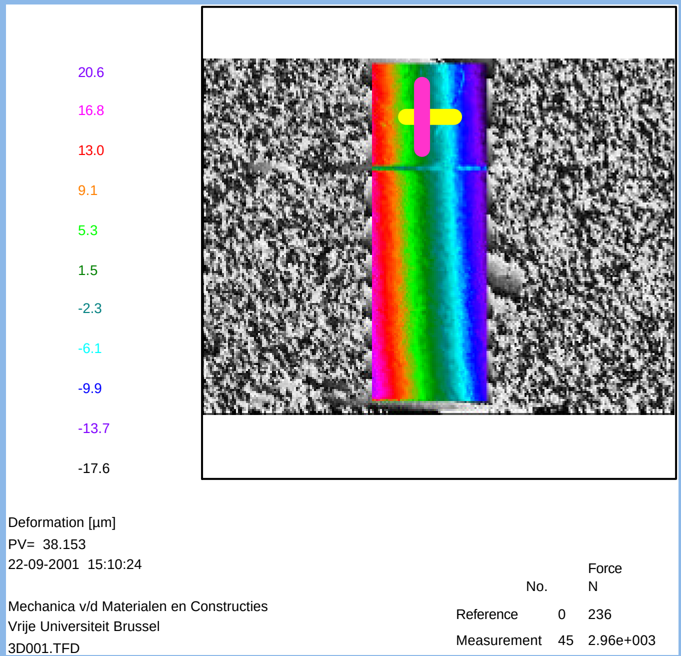
ε_{xy}

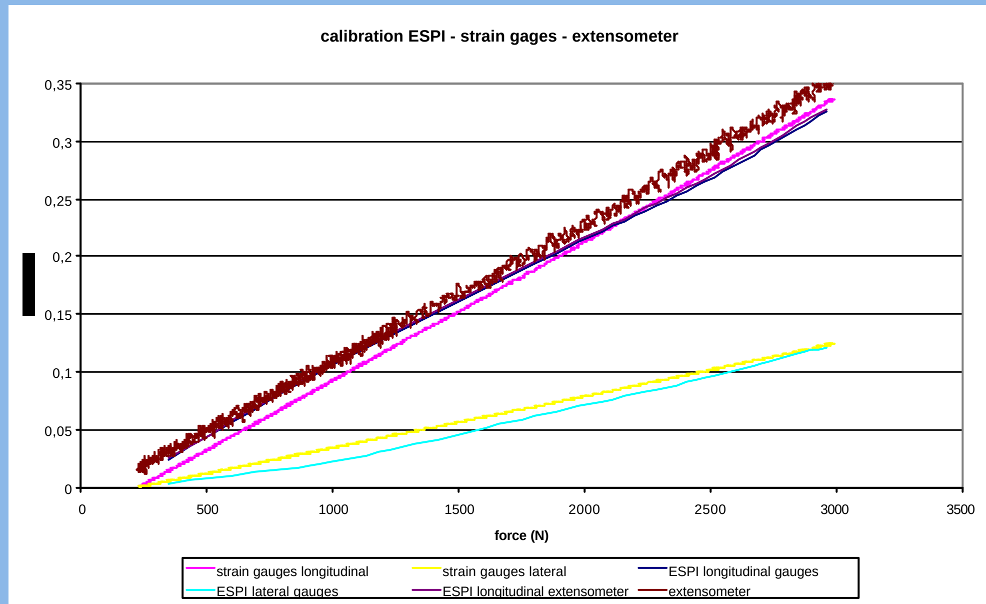


ε_{yx}



Calibration ESPI technique

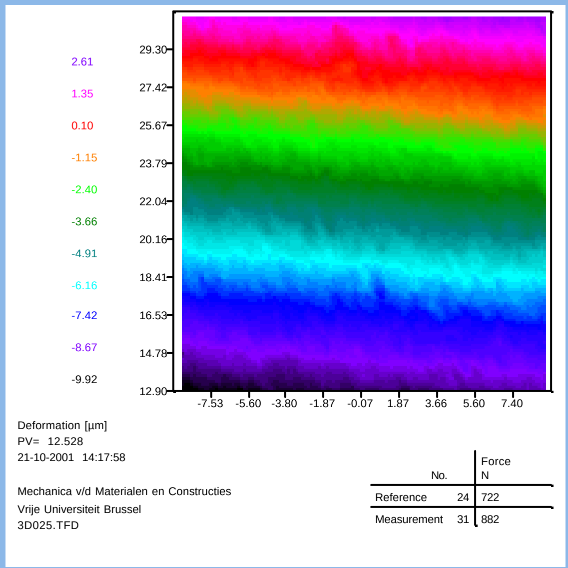




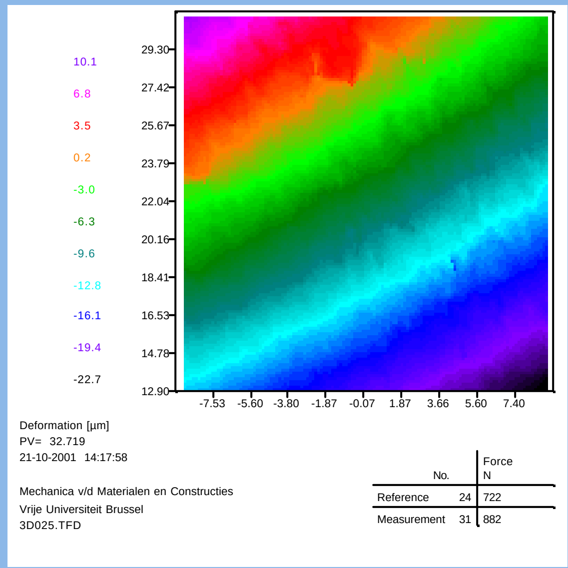
- good correspondence with gages and extensometer
- validation of the method quantitatively

ESPI monitoring vs. microscopic inspection

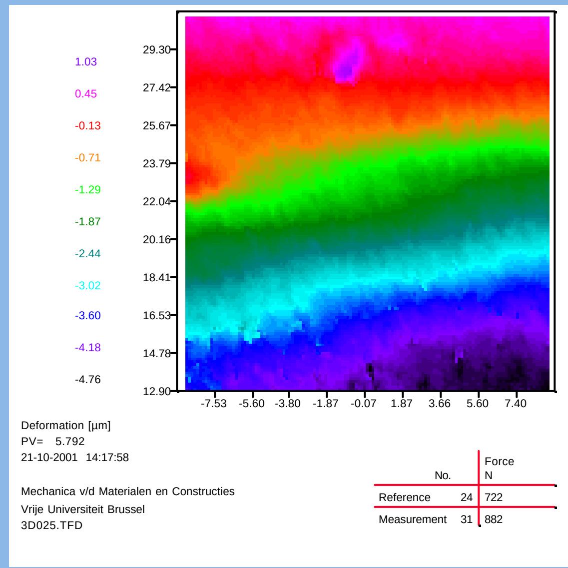
x-displacement



y-displacement



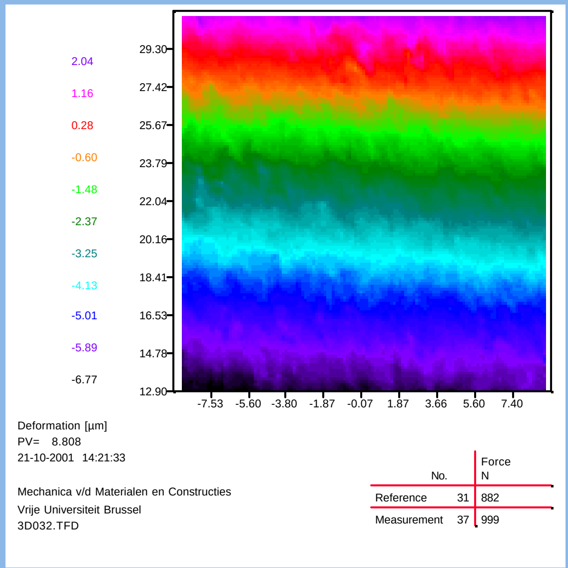
z-displacement



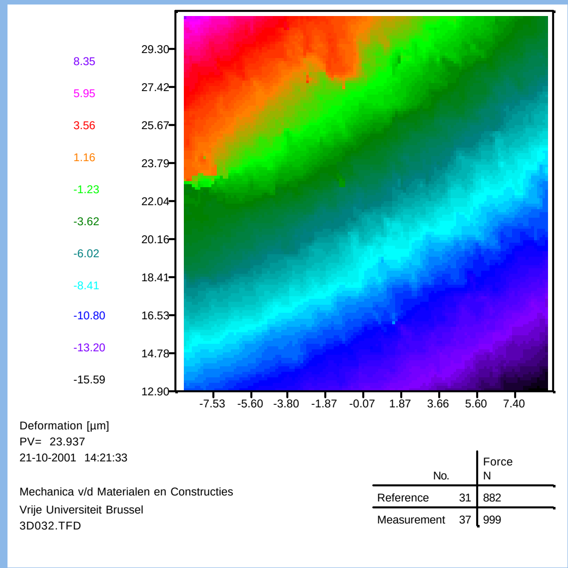
24.2MPa => 34.8MPa

ESPI monitoring vs. microscopic inspection

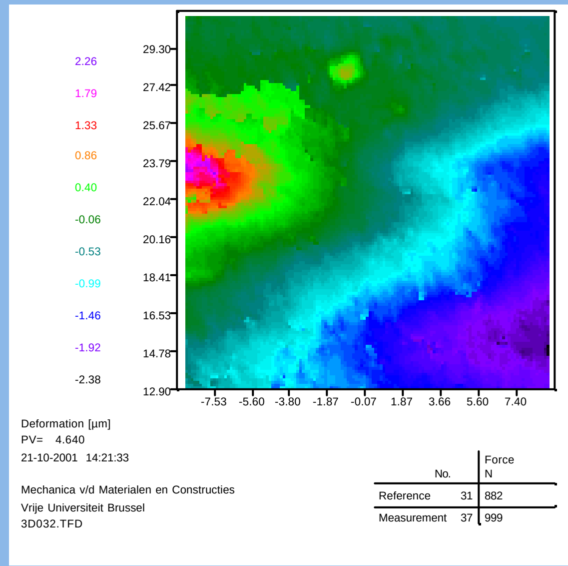
x-displacement



y-displacement



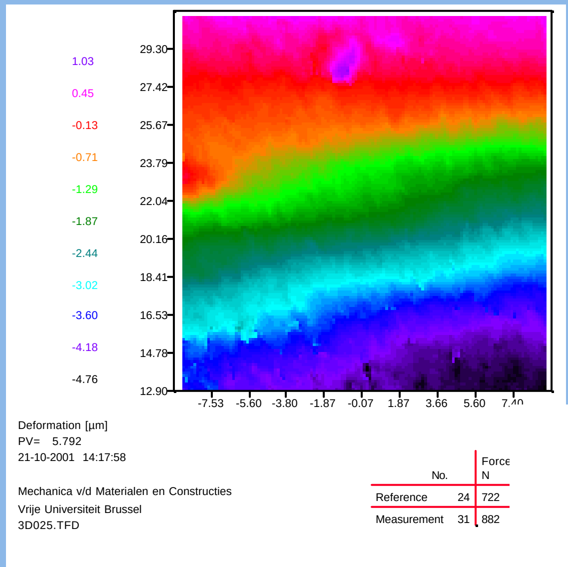
z-displacement



35.6MPa => 40.3MPa

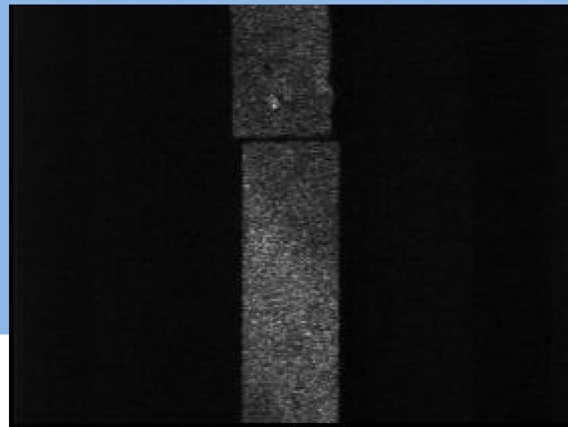
ESPI monitoring vs. microscopic inspection

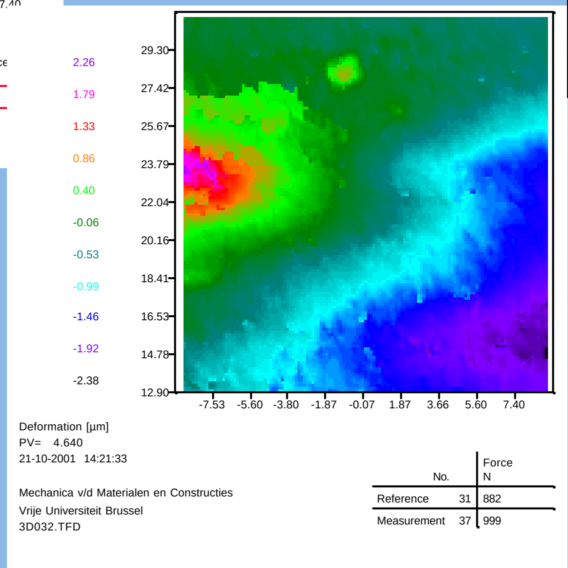
z-displacement

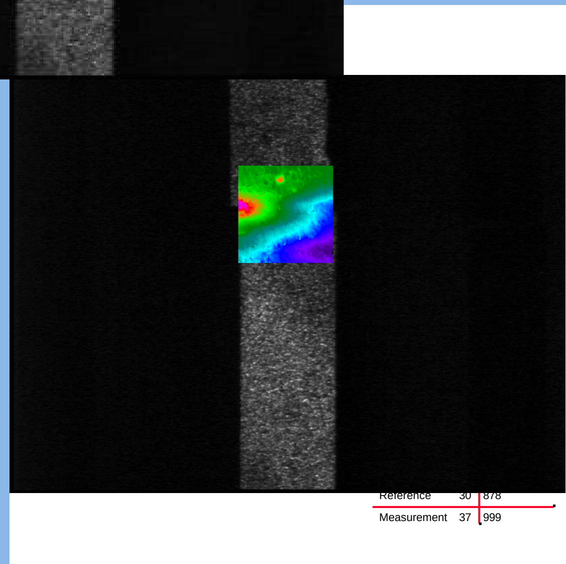


24.2MPa => 34.8MPa

35.6MPa => 40.3MPa+ 30min creep

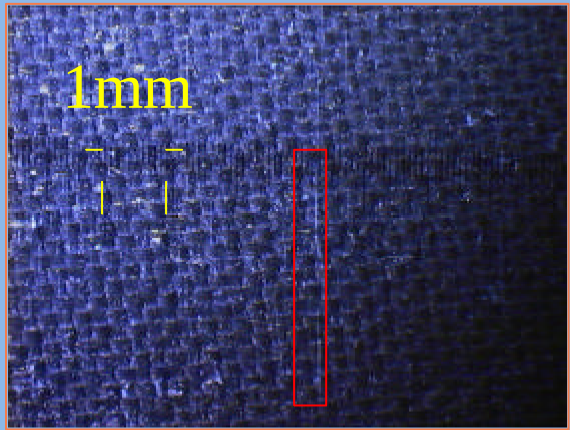




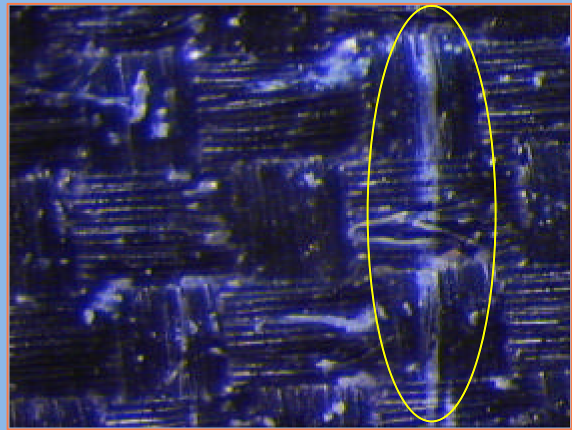


35.6MPa => 40.3MPa

microscopic inspection of superficial cracks



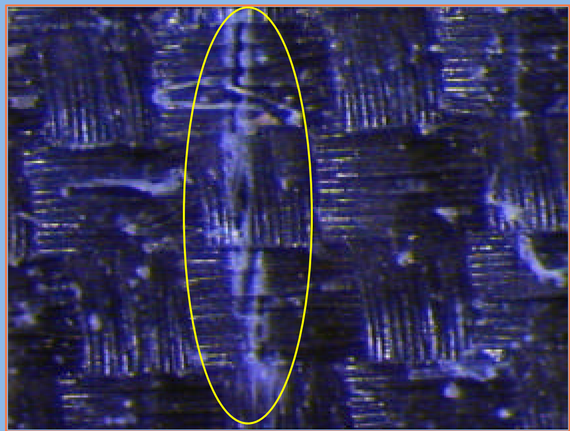
initiated crack unloaded



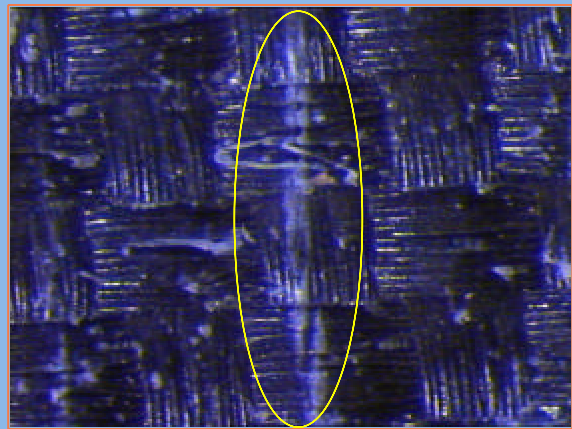
magnification 15x

load direction

fibre direction



crack at 40MPa stress load



crack after rupture

3D - ESPI conclusion

Characteristics

- full field measurement
- measurement on the outer surface
- high resolution *30 nm*, sensitivity for local, heterogeneous strain effects (better than 0.01% strain)
- scale of measurement commensurate with inhomogeneities

disadvantages

- sensitive to vibration noise
- sensitive to light sources with laser frequency

General conclusion

- classic strain measurement technique not appropriate
    - lack of resolution
    - local measurement
- critical strain behaviour at elevated stress conditions
- short term experiments vs. long term behaviour