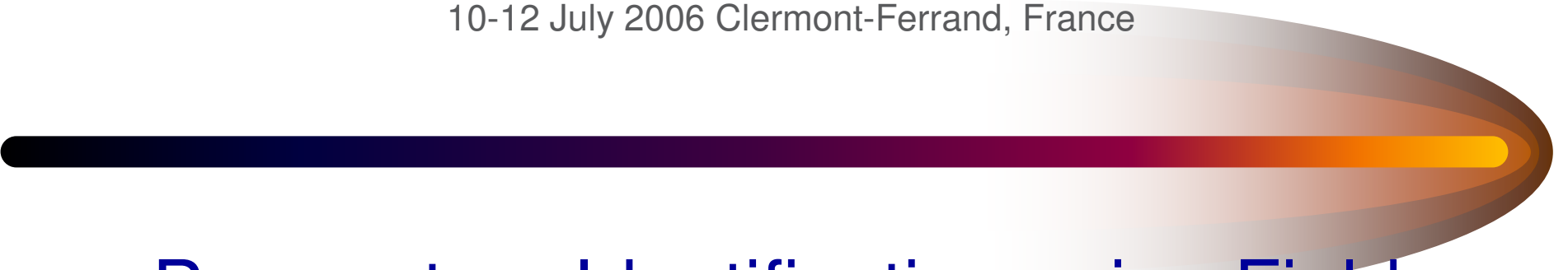


Photomechanics

International Conference on full-field measurement techniques and their applications in experimental solid mechanics

10-12 July 2006 Clermont-Ferrand, France

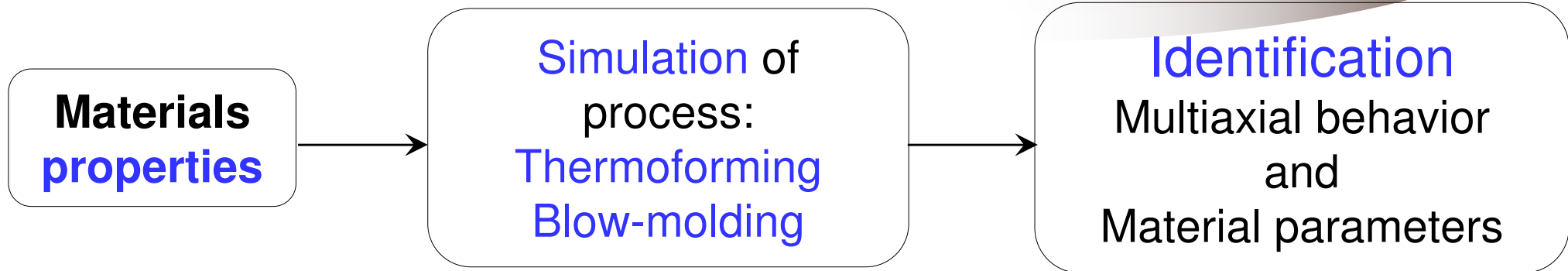


Parameters Identification using Field Measurements of Polymer Membranes during Bubble Inflation Technique

[Samia HMIDA-MAAMAR](#), Fabrice SCHMIDT, Laurent ROBERT, Vincent VELAY

CROMeP, Ecole des Mines d'Albi Carmaux

Introduction



- **Identification** of material parameters:
 - Extraction of contour
 - Full field measurements
 - **Inverse analysis** using numerical simulations such as **Finite Element Method**

Outline



- Experimental set-up:
 - Elongational Rheometer
- Parameters identification:
 - Extraction of contour
 - Tensile test
 - Full-field measurement
- Conclusion and prospects

Experimental set-up: Bubble inflation rheometer

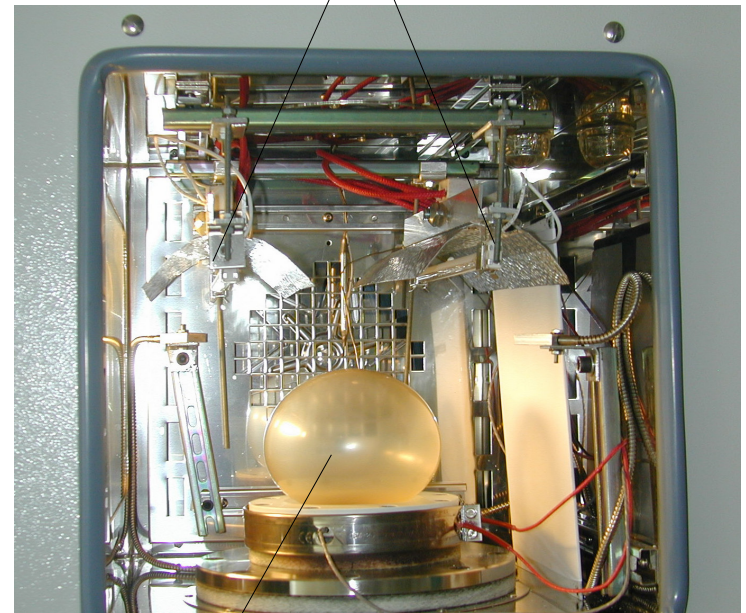
CCD Camera



Pyrometer

Oven

IR Lamps



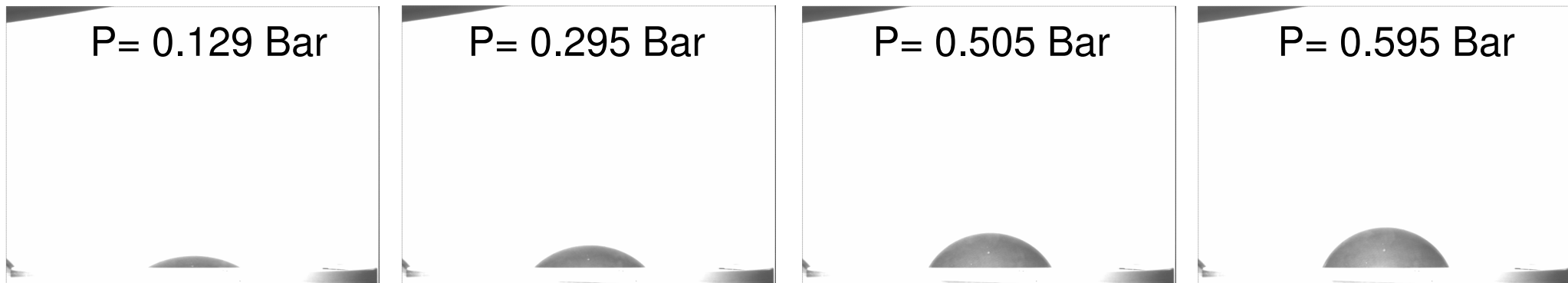
Pressure sensor

Elastomer bubble

Measurement using one CCD camera

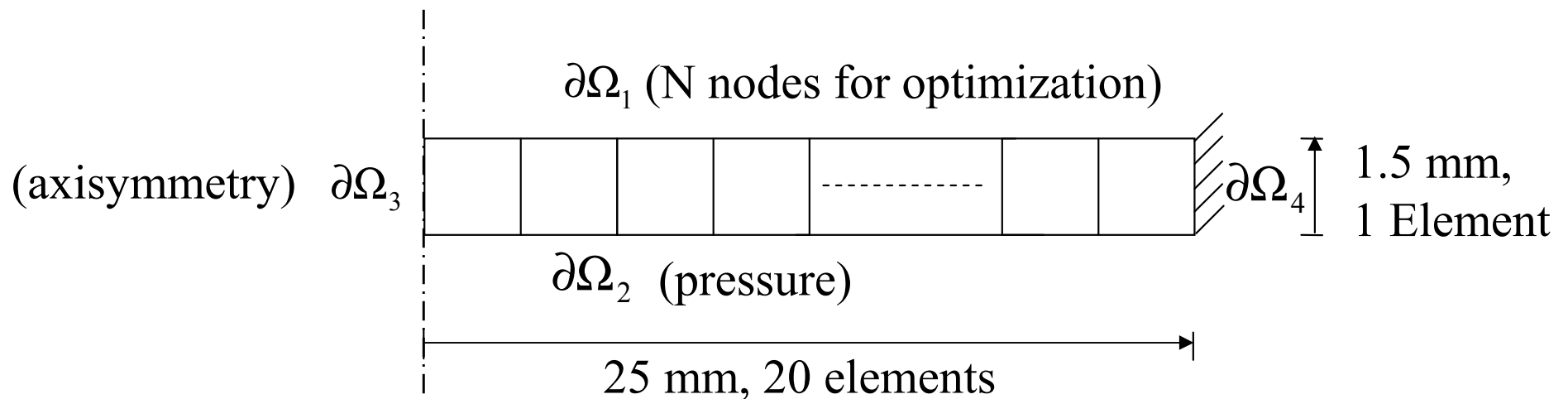
- Natural rubber samples:
 - Diameter: 90 mm / Thickness: 1.5 mm
- Camera XC-75CE:
 - 25 mm f 1.4 / Resolution: 795 (H) * 596 (V)

Example of rubber bubble inflations:



Numerical modeling

- Commercial FEM Software ABAQUS®:
 - 2D quadratic elements, axisymmetric CAX8H



- Hyper Elastic Behavior: Mooney Rivlin

$$w = w(I_1, I_2) = C_{10}(I_1 - 3) + C_{01}(I_2 - 3)$$

C_{10} and C_{01} : material parameters

Optimization algorithm

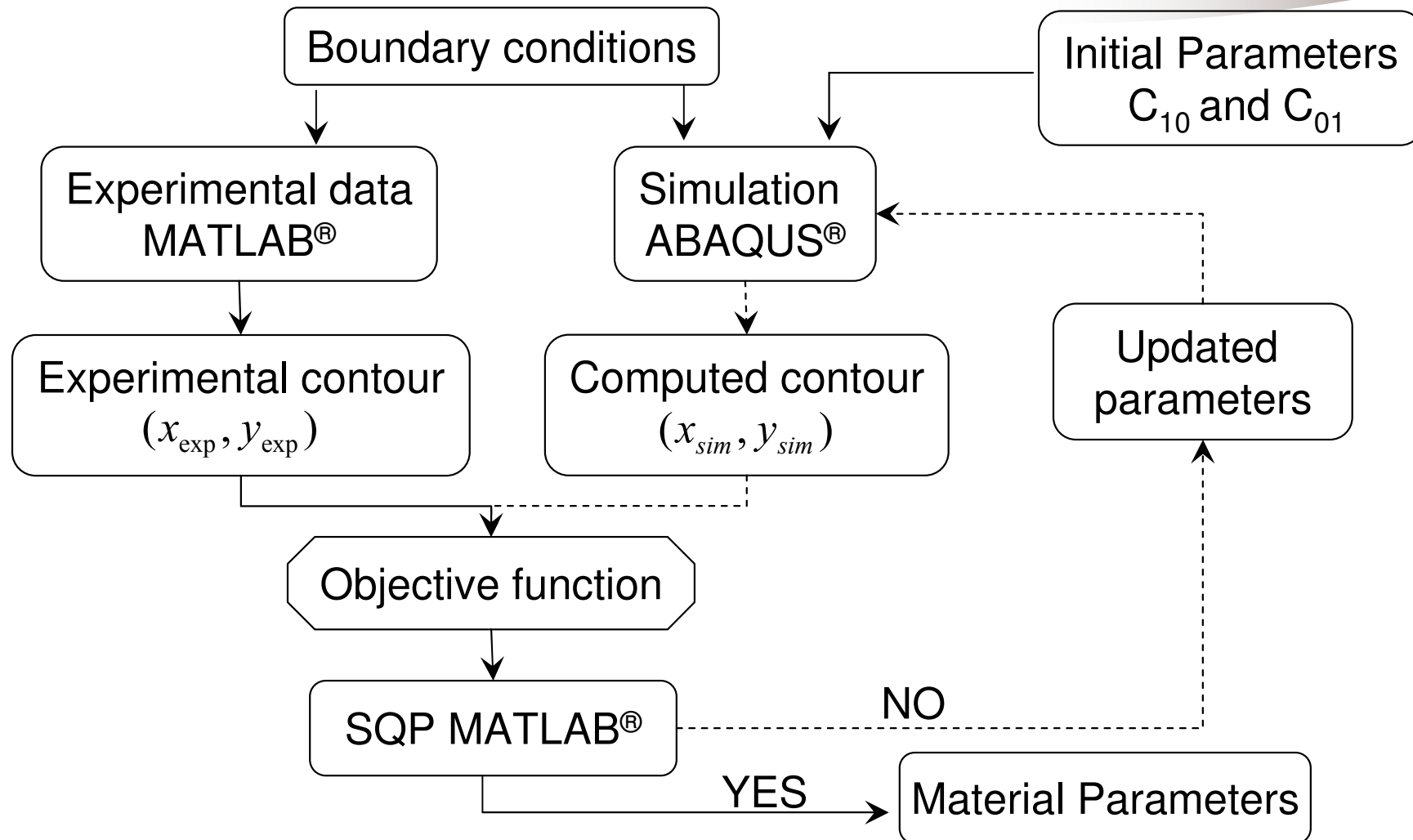
- Interface ABAQUS® and MATLAB®
- Sequential Quadratic Programming Method (SQP)
- Function ‘fmincon’ of the optimization module of MATLAB® was used

- Objective function:
$$\Phi = \sqrt{\sum_{i=1}^N (y_{sim}^i - f(x_{sim}^i))^2} / \sqrt{\sum_{i=1}^N (f(x_{sim}^i))^2}$$

(x_{sim}, y_{sim}) : Computed Contour

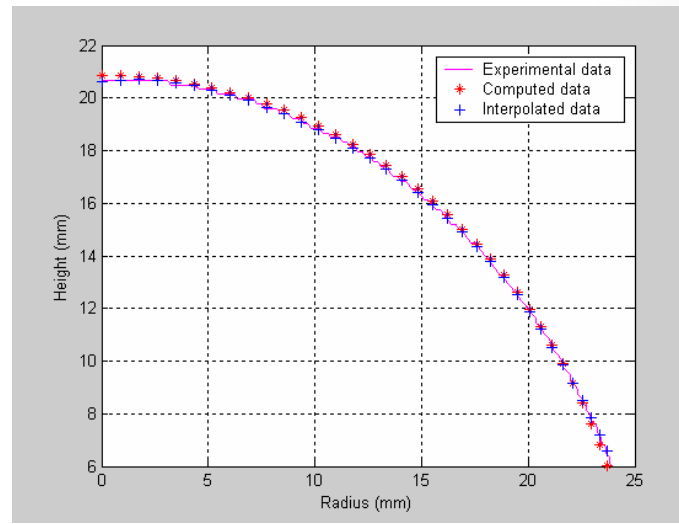
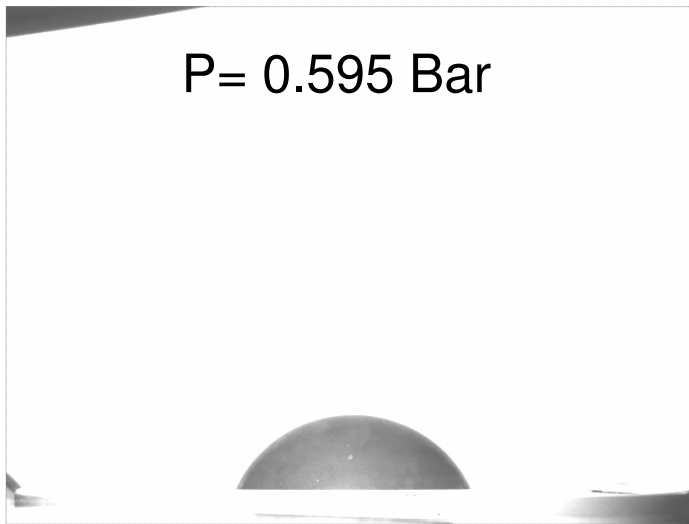
$f(x)$: Interpolation function of experimental contour (x_{exp}, y_{exp})

Optimization principle



Identification: extraction of contour (1)

Result for a given pressure value:



- $C_{10} = 0.134$ MPa ,
- $C_{01} = 0.09954$ MPa
- Objective = 0.0105

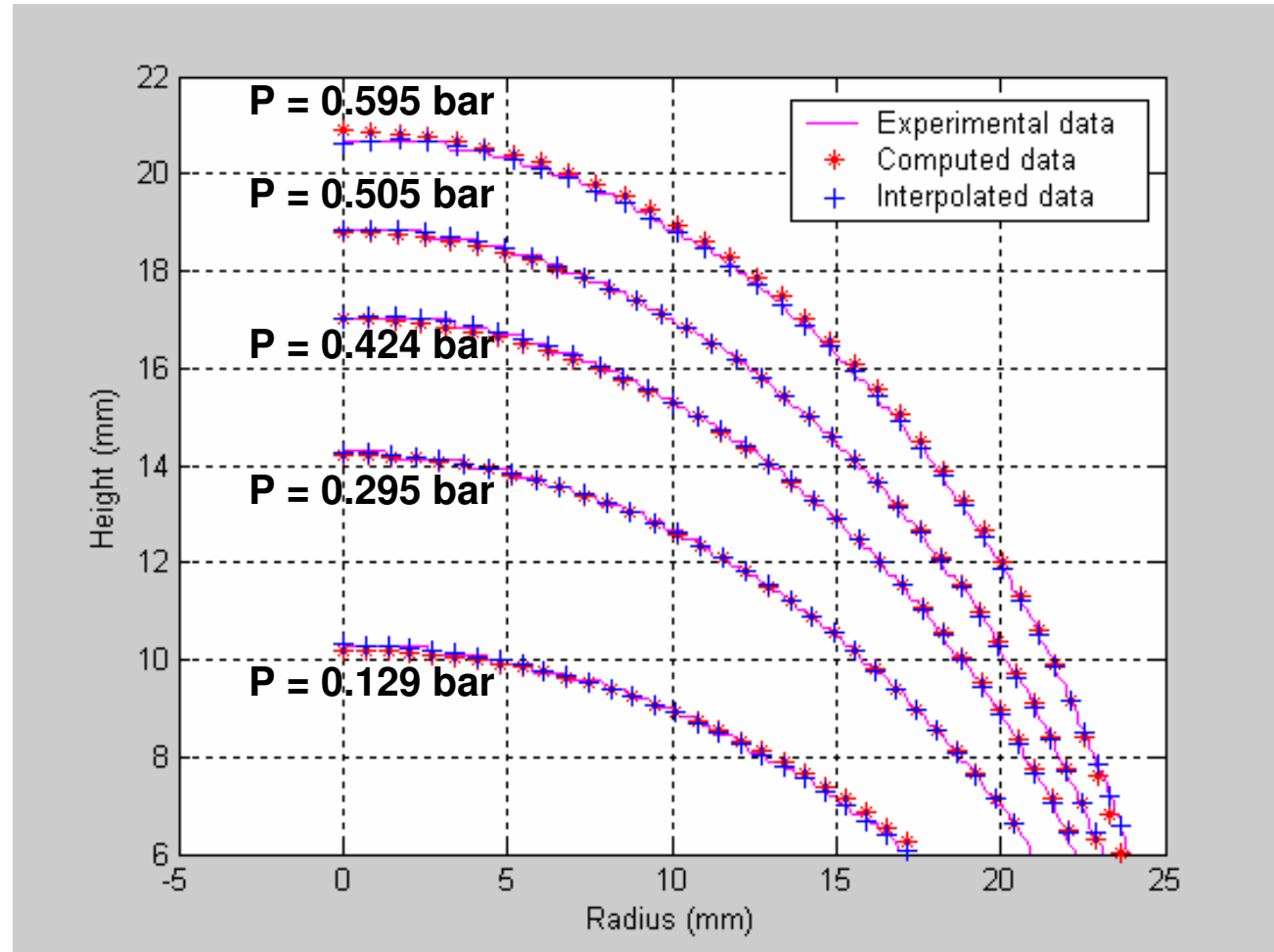
Summary results for 5 pressure steps:

Pressure (Bar)	0.129	0.295	0.424	0.505	0.595
C_{10} (MPa)	0.1343	0.13677	0.13291	0.13751	0.134
C_{01} (MPa)	0.09913	0.09651	0.09971	0.0968	0.09954

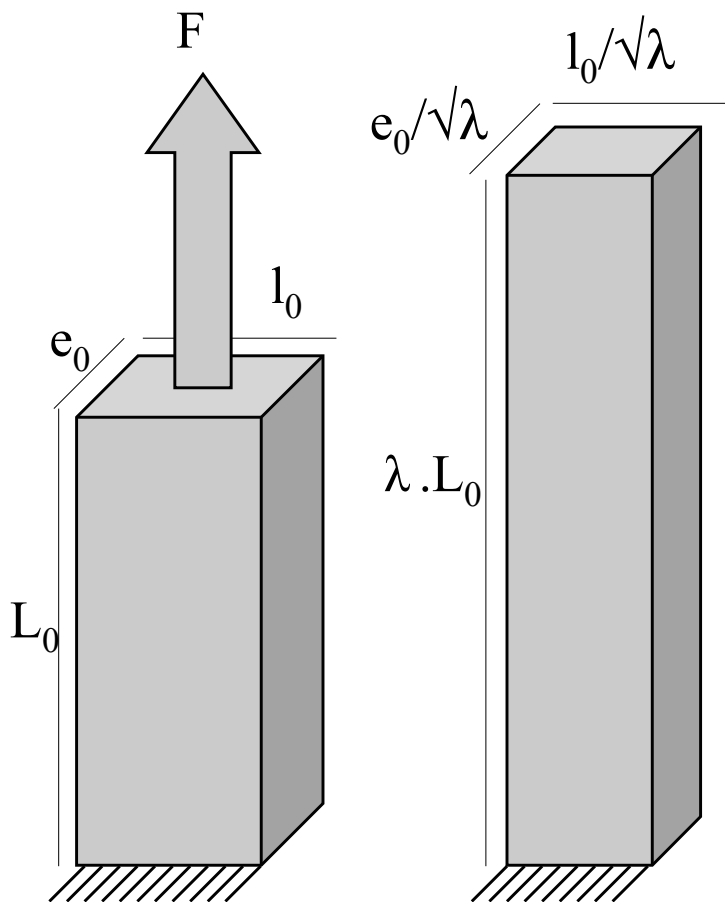
Identification: extraction of contour (2)

Global identification:

- for all the values of pressure, only one couple of parameter is identified :
 - $C_{10} = 0.13298$ MPa
 - $C_{01} = 0.10011$ MPa
 - Objective = 0.0061



Stereo-correlation technique: tensile test



- Natural rubber rectangular samples:
 - Length L_0 : 90 mm
 - Width l_0 : 25 mm
 - Thickness e_0 : 4 mm
- Boundary conditions:
 - Vertical load F
 - The lower face is fixed
- Stereo-correlation technique using Vic-3D[®] software



Green's Lagrangian strain

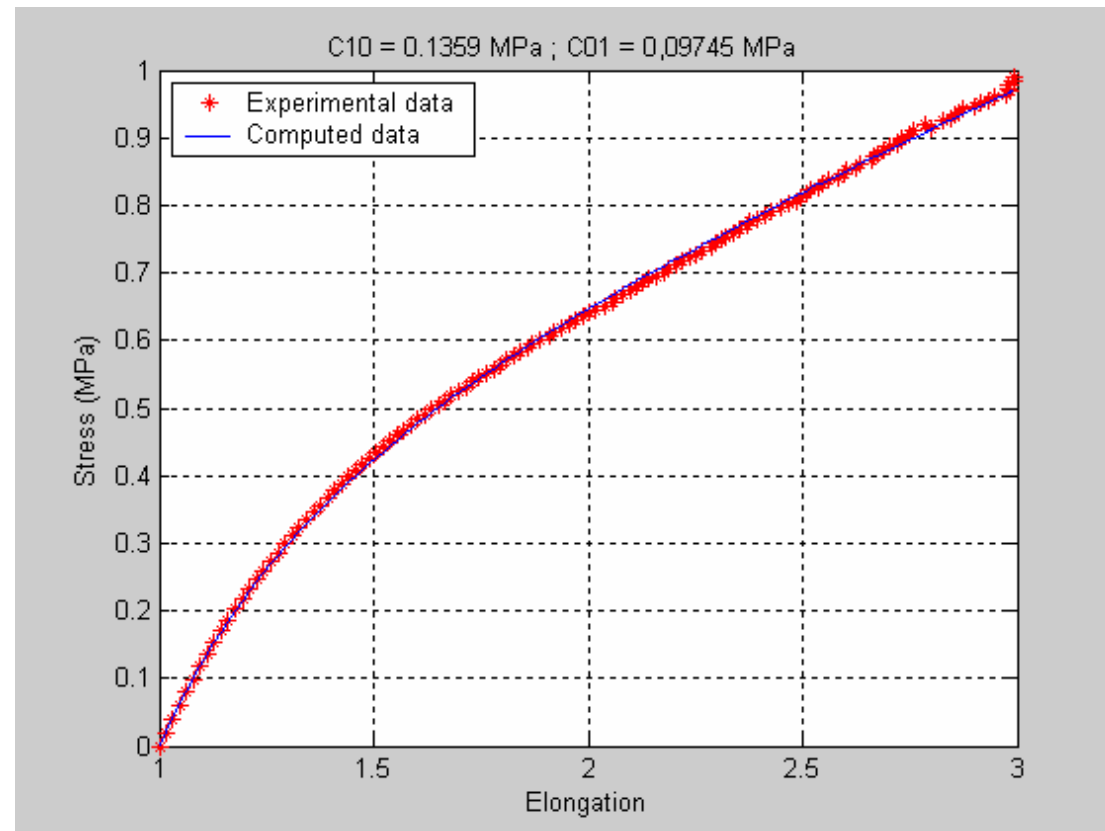
Identification on tensile test

- Tensile stress:
$$\sigma = \frac{F}{S_0} = 2C_{10} \left(\lambda - \frac{1}{\lambda^2} \right) + 2C_{01} \left(1 - \frac{1}{\lambda^3} \right)$$

- F: load
- S_0 : initial surface
- λ : stretch ratio calculated using the experimental strain value

- Identified Parameters:

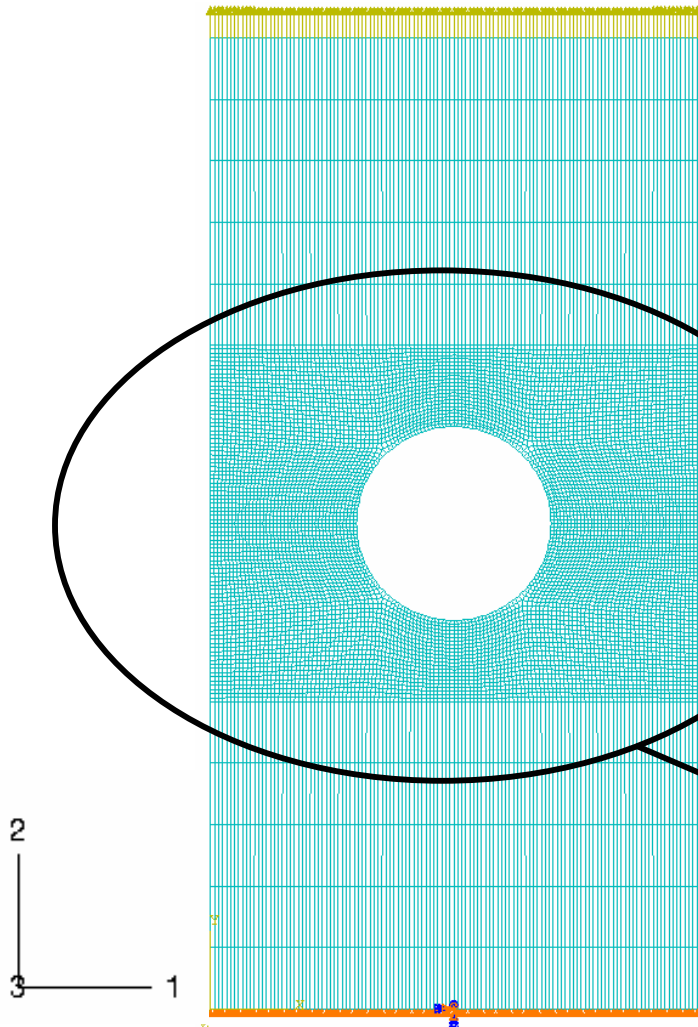
- $C_{10} = 0.1359$ MPa
- $C_{01} = 0.09745$ MPa
- Objective = 0.0087



=> Values are closed to those obtained using bubble inflation technique

Identification based on full field measurements

Description of the methodology:

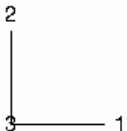
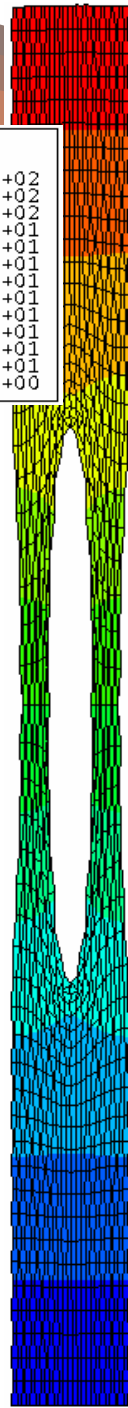
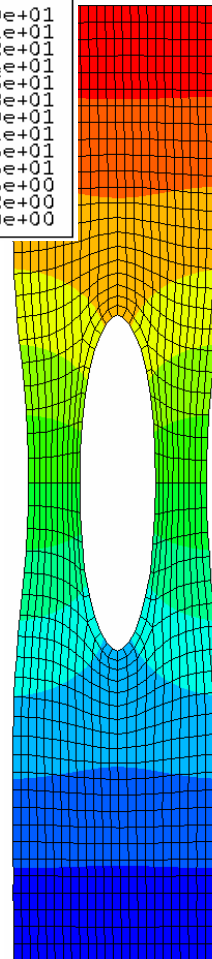
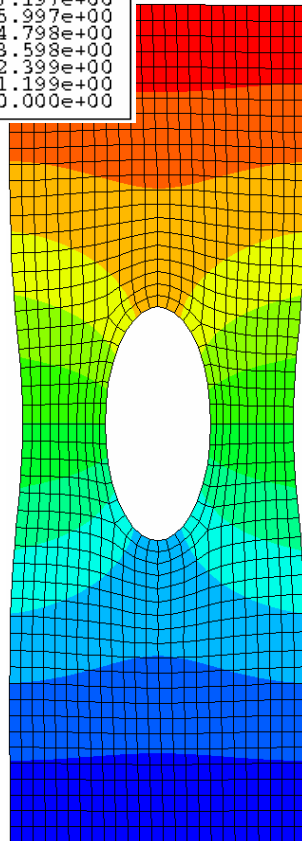
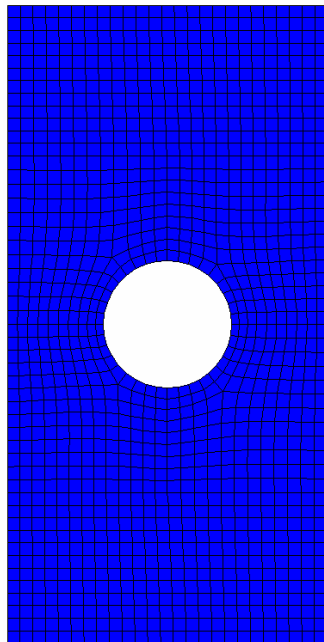
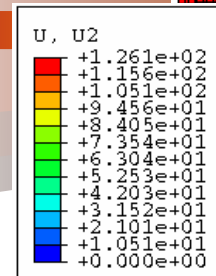
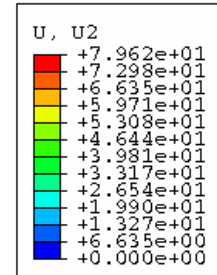
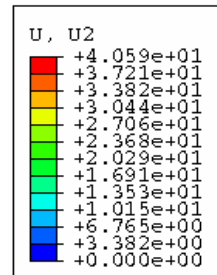
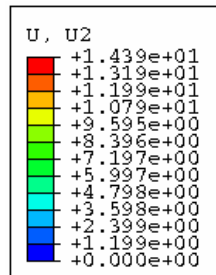
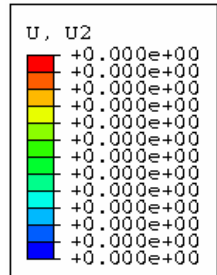


- Natural rubber drilled rectangular samples:
 - Length: 50 mm
 - Width: 25 mm
 - Thickness: 4 mm
 - Diameter of the hole: 10 mm
- Boundary conditions:
 - Load imposed on upper face nodes
 - Lower face is fixed

This part represents the field measurements (pixels of the camera)
=> FE « simulated » measurements

Numerical modeling: 4 tensile steps

(4 tensile steps are used in the identification procedure)



Identification based on full fields

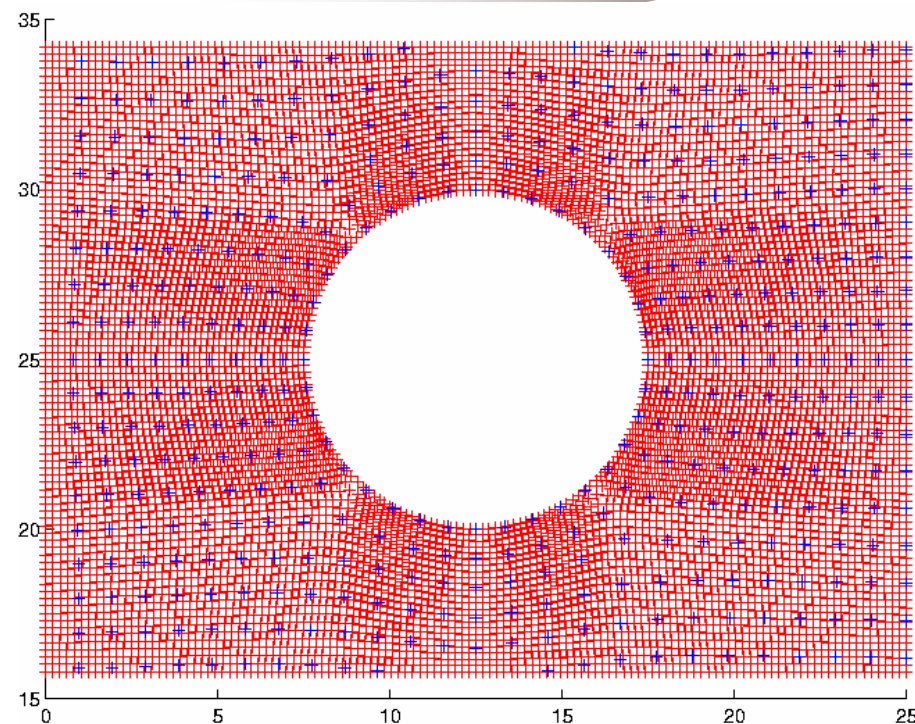
(In order to assess the algorithm, the procedure used « simulated » measurements)

- Put in correspondence of meshes

— : Experimental mesh
+ : FEM mesh

- Optimization algorithm (SQP)
- Objective function:

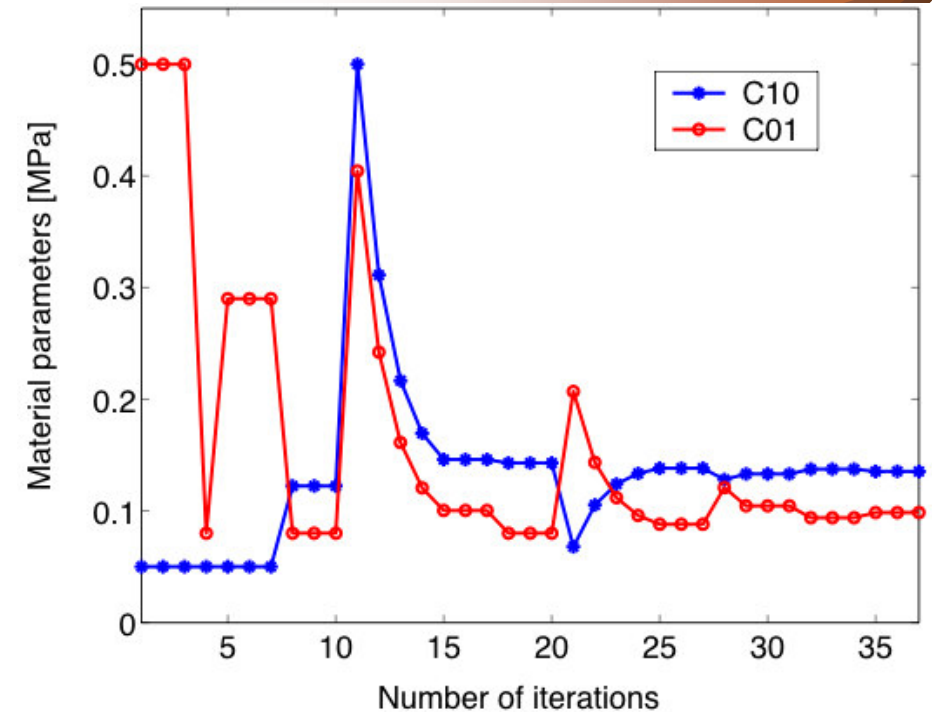
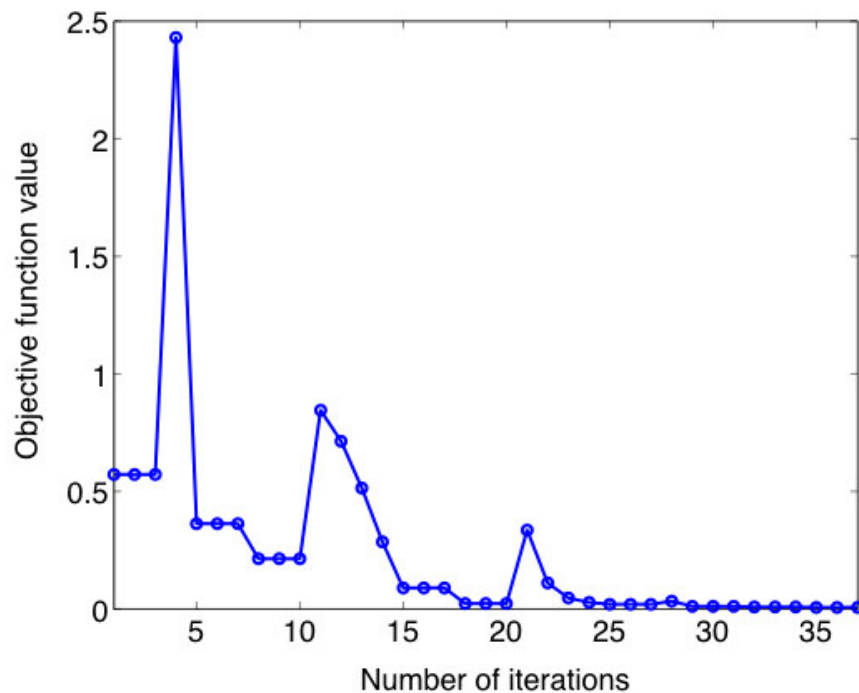
$$\Phi = \frac{1}{N_{image}} \sum_{i=1}^{N_{image}} \left[\frac{1}{N_{node}} \sum_{j=1}^{N_{node}} \frac{\left\| \vec{U}_{simu,j}^i - \vec{U}_{exp,j}^i \right\|}{\left\| \vec{U}_{exp,j}^i \right\|} \right]$$



Identification based on full fields: convergence

Initial and range parameter values:

- $C_{10}^{\text{init}} = 0.05$ MPa,
- $C_{01}^{\text{init}} = 0.50$ MPa,
- $0.05 < C_{10} < 0.5$ [MPa]
- $0.08 < C_{01} < 0.5$ [MPa]

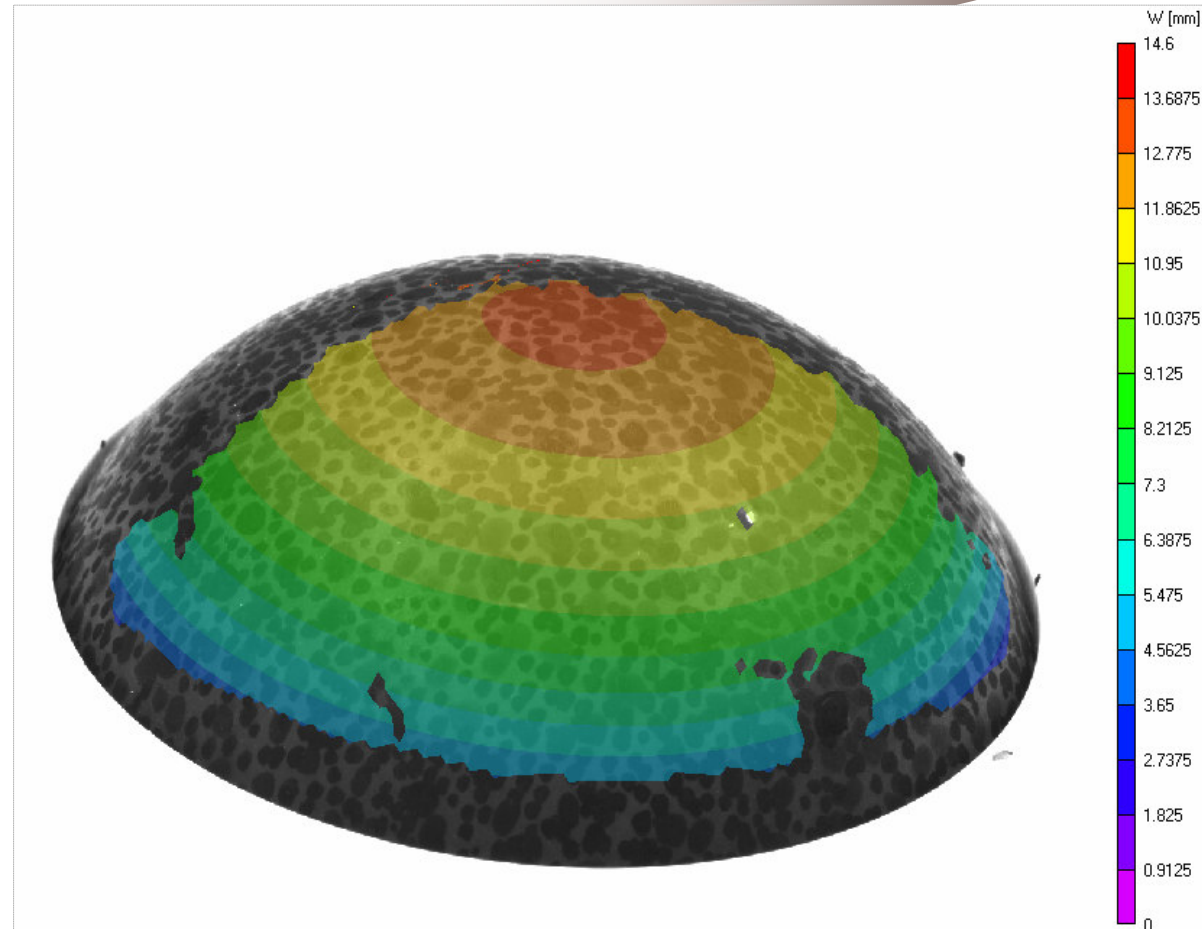


- Identified parameters:
 - $C_{10} = 0.13535$ Mpa
 - $C_{01} = 0.098439$ MPa
 - Objective = 0.0063055

=> Values are closed to those obtained using previous techniques

Stereo-correlation technique: Elongational rheometer (1)

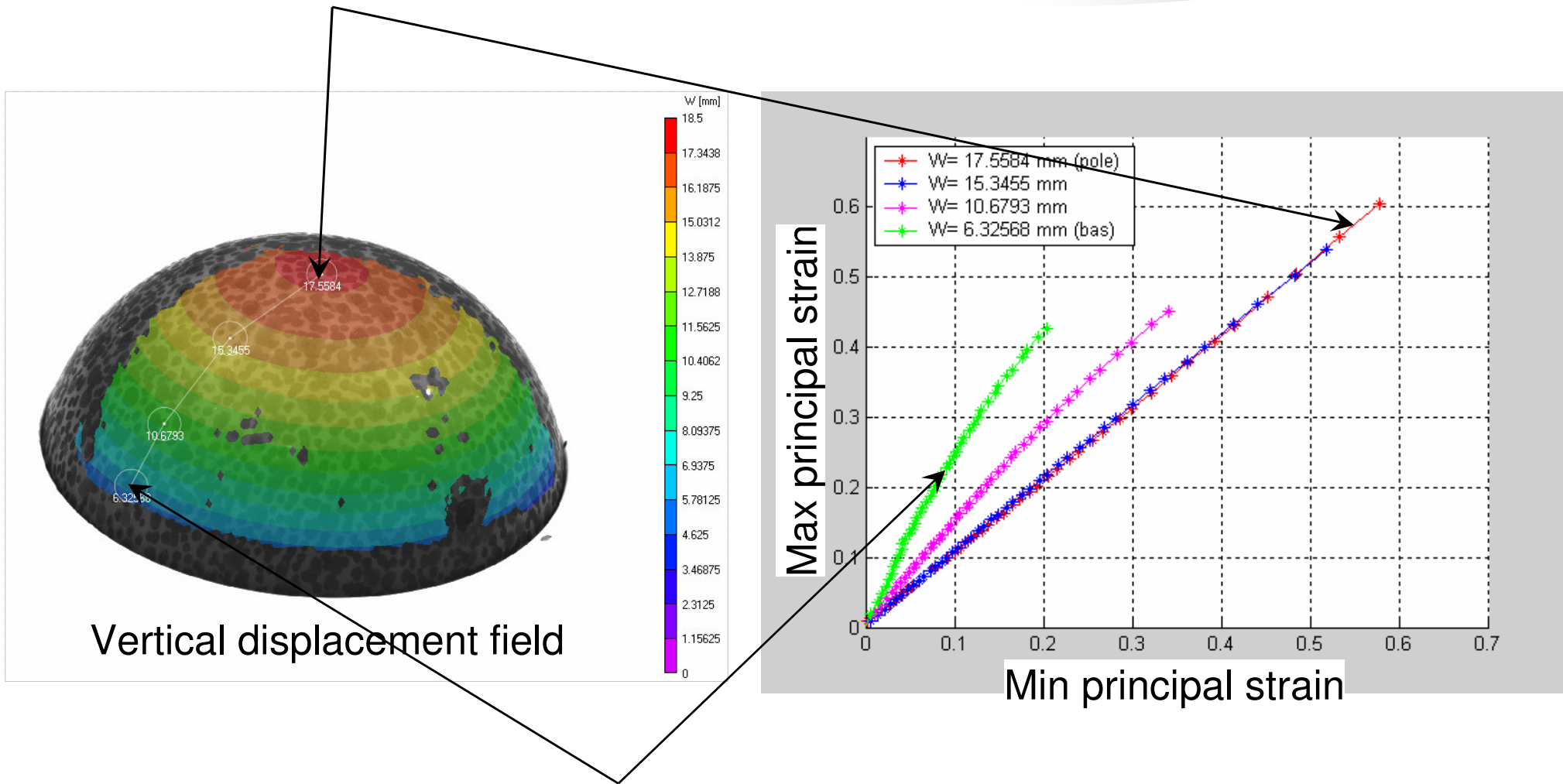
- Natural rubber samples:
 - Diameter: 90 mm / Thickness: 1.5 mm
 - Two CCD cameras: RETICA QICAM (QIMAGING)
 - Lens: AF 28 – 200mm / Resolution: 1360 * 1036 pixels
- Digital Image Stereo-Correlation software: Vic-3D®



Vertical displacement field obtained by stereo-correlation

Stereo-correlation technique: Elongational rheometer (2)

Purely equi-biaxial behavior



Vertical displacement field

Max principal strain

Min principal strain

Non-Purely equi-biaxial behavior

Conclusion and prospects

Conclusion :

- Behavior identification using **2D contour extraction** coupled to **inverse method** of **rubber** membrane
- Procedure assessment of behavior identification using **full-field measurement** during **tensile test**
- Preliminary results of behavior identification using **3D full-field measurement** of **rubber** membrane using **bubble inflation** technique

Future works :

- Parameters identification using 2D and 3D full field measurement (experimental) values
- Behavior identification using **extraction contour 2D** and using **field measurement 3D** of PET-type **polymer** membrane