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# Parameters identification of hyperelastic constitutive model by instrumented indentation of filled silicone rubber.

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Particle-filled elastomers are widely used in industries ranging from civil engineering to aeronautics and automotive. The specific phenomena of the mechanical behaviour of these materials are well known at the macro scale (hyperelasticity, viscoelasticity, Mullins effect). Indentation is therefore a well-suited method for studying them at lower scales. However, the indentation of polymers and therefore elastomers leads to experimental difficulties (surface state, adhesion). As a result, a combination of **experimental** and **numerical** studies is required. To that end, O. Ezzaamari et al. [1] show the possibility to use the entire indentation curve to identify parameters of hyperelastic constitutive models using model reduction. The main purpose of this work is to study the actual application of this identification methodology to filled Polydimethylsiloxane rubber. Experimental tests for identification purposes are carried out using spherical indentation. The induced stress state is studied numerically in order to compare the results with equivalent homogeneous macroscopic tests.

## Studied material

### Silicone based rubber vulcanized at RT (RTV)

Polydimethylsiloxane rubber, filled with SiO<sub>2</sub> and CaCO<sub>3</sub>

### Mechanical behaviour

No time dependency at room temperature ( $T_g = -120\text{ °C}$ )

Incompressibility ( $\nu = 0.5$ )

## Indentation test

### Tools

Bruker Hysitron TI 980 Triboindenter

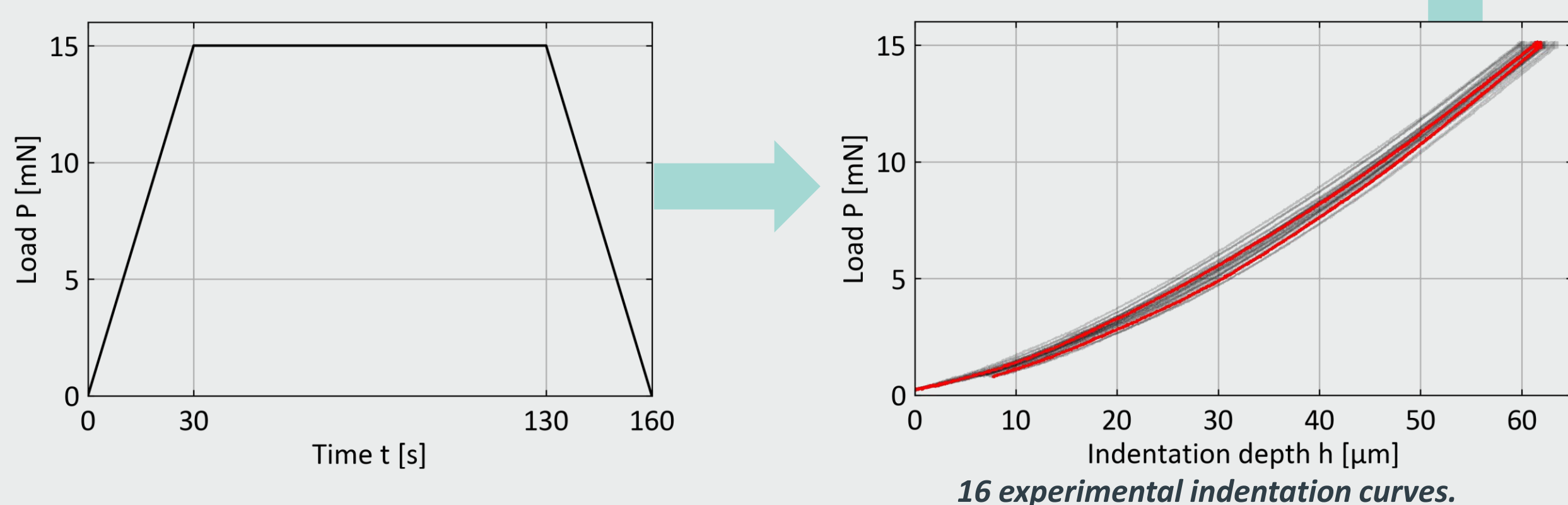
Spherical tip,  $R = 100\text{ }\mu\text{m}$

Measure range,  $70\text{ }\mu\text{N} \leq P \leq 20\text{ N}$  |  $0.5\text{ nm} \leq h \leq 80\text{ }\mu\text{m}$

### Protocol

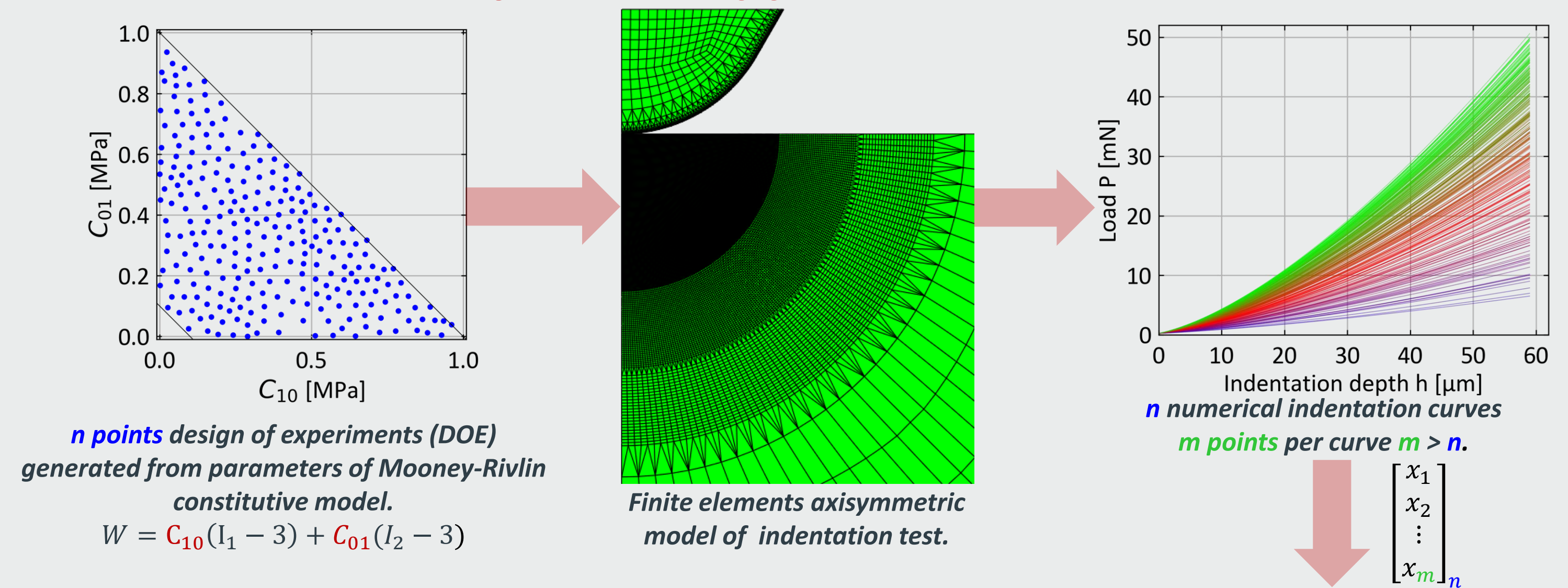
4 x 4 indentation matrix  
150  $\mu\text{m}$  between positions.

$P_{max} = 15\text{ mN}$   
 $\dot{P} = 0.5\text{ mN}\cdot\text{s}^{-1}$   
 $T = 23.5\text{ °C}$



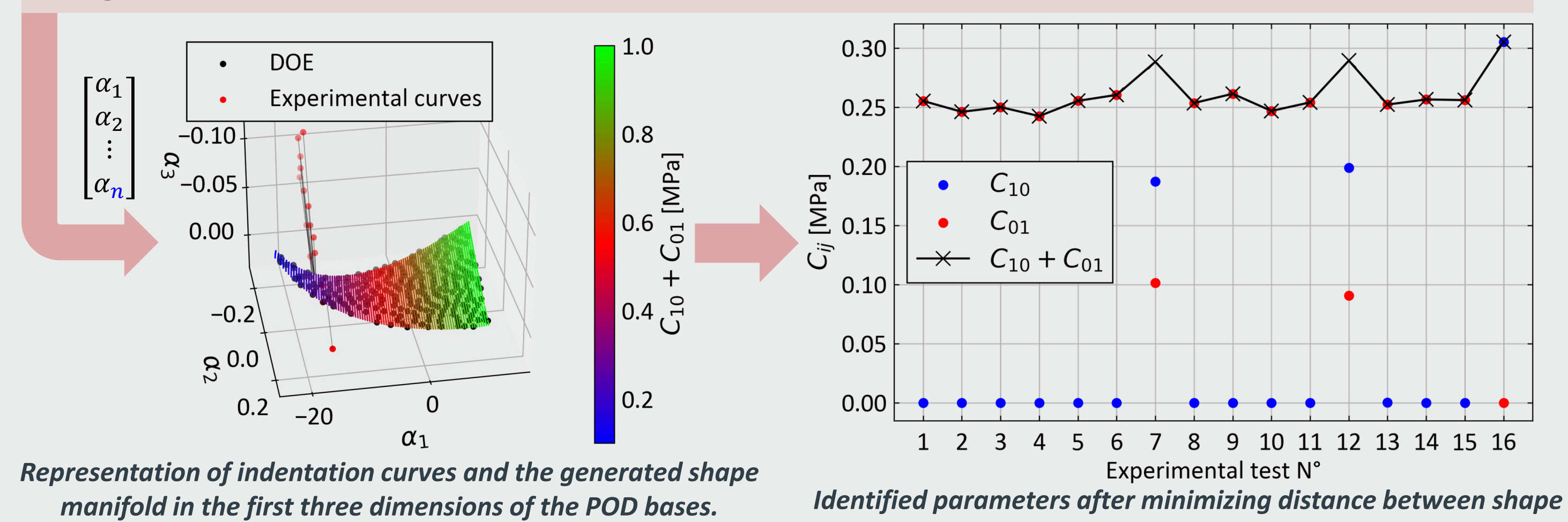
Isolation of loading curves and discretisation to define them as input vectors for POD.  
 $\begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_m \end{bmatrix}$

## Identification approach and results



### Proper Orthogonal Decomposition (POD)

Construction of 2D shape manifold in a  $n$ -dimensional POD bases generated from the variance of the numerical indentation curves.



- Although spherical indentation is undoubtedly influenced by both  $C_{10}$  and  $C_{01}$  coefficients (2D manifold), the indentation curves seem to mainly depend on their sum. That leads to bring experimental points out of the manifold on  $\alpha_2$  direction and to identify inconsistent parameters. Some experimental studies show that  $C_{10}$  is physically related to the crosslinking density [2], since crosslinked material is studied  $C_{10} > 0\text{ MPa}$ .

## Spherical indentation stress state

### Hencky's strain (logarithmic strain):

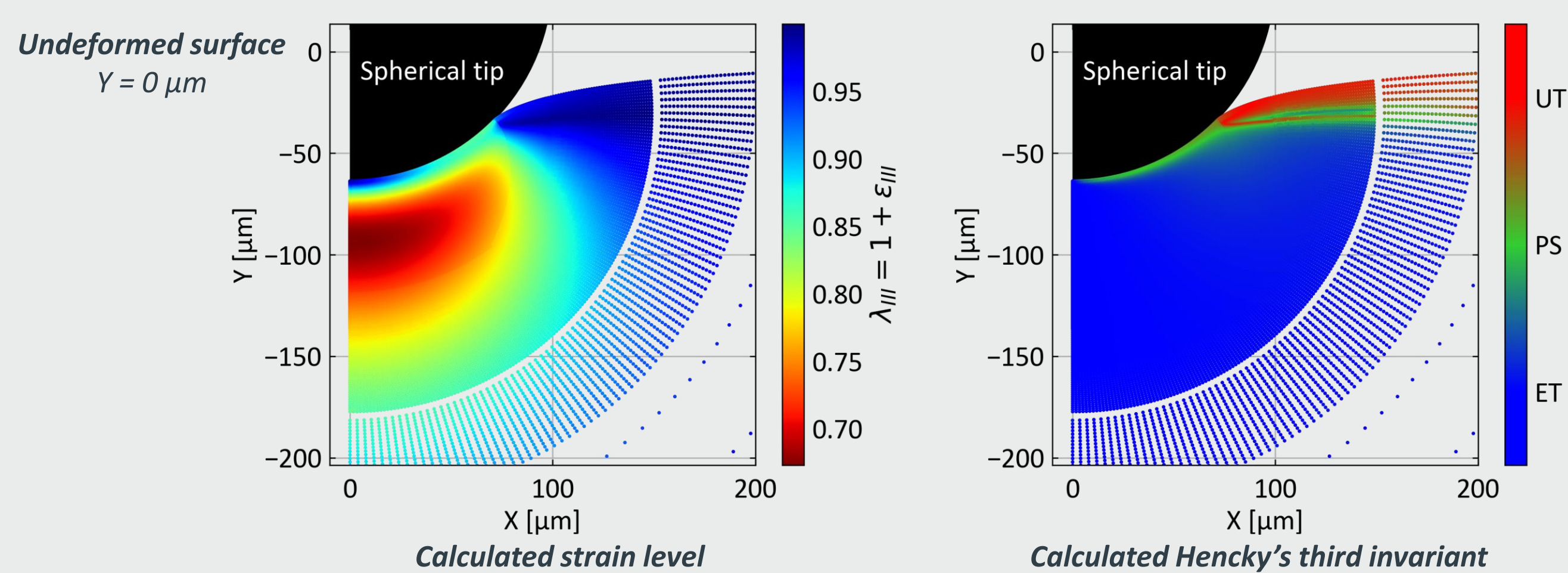
$$h = \frac{1}{2} \ln B$$

$B$ : Left Cauchy-Green tensor

### Third invariant is computed at each mesh nodes [3].

$$\rho = \frac{3h_2}{h_3 - h_1}$$

$\rho = 1 \rightarrow$  Uniaxial tension (UT)  
 $\rho = 0 \rightarrow$  Pure shear (PS)  
 $\rho = -1 \rightarrow$  Equibiaxial tension (ET)



- Spherical indentation mainly induces equibiaxial tension under the tip which is equivalent to uniaxial compression with the incompressibility hypothesis [4].

## Uniaxial compression test

### Cylindrical samples

$h_0 = 32\text{ mm}$   
 $d_0 = 16\text{ mm}$

### Experimental protocol

$\lambda_{min} = 0.8 \equiv \epsilon_{max} = 20\%$   
 $\dot{\epsilon}_0 = 10^{-2}\text{ s}^{-1}$   
 $T = 23.5\text{ °C}$

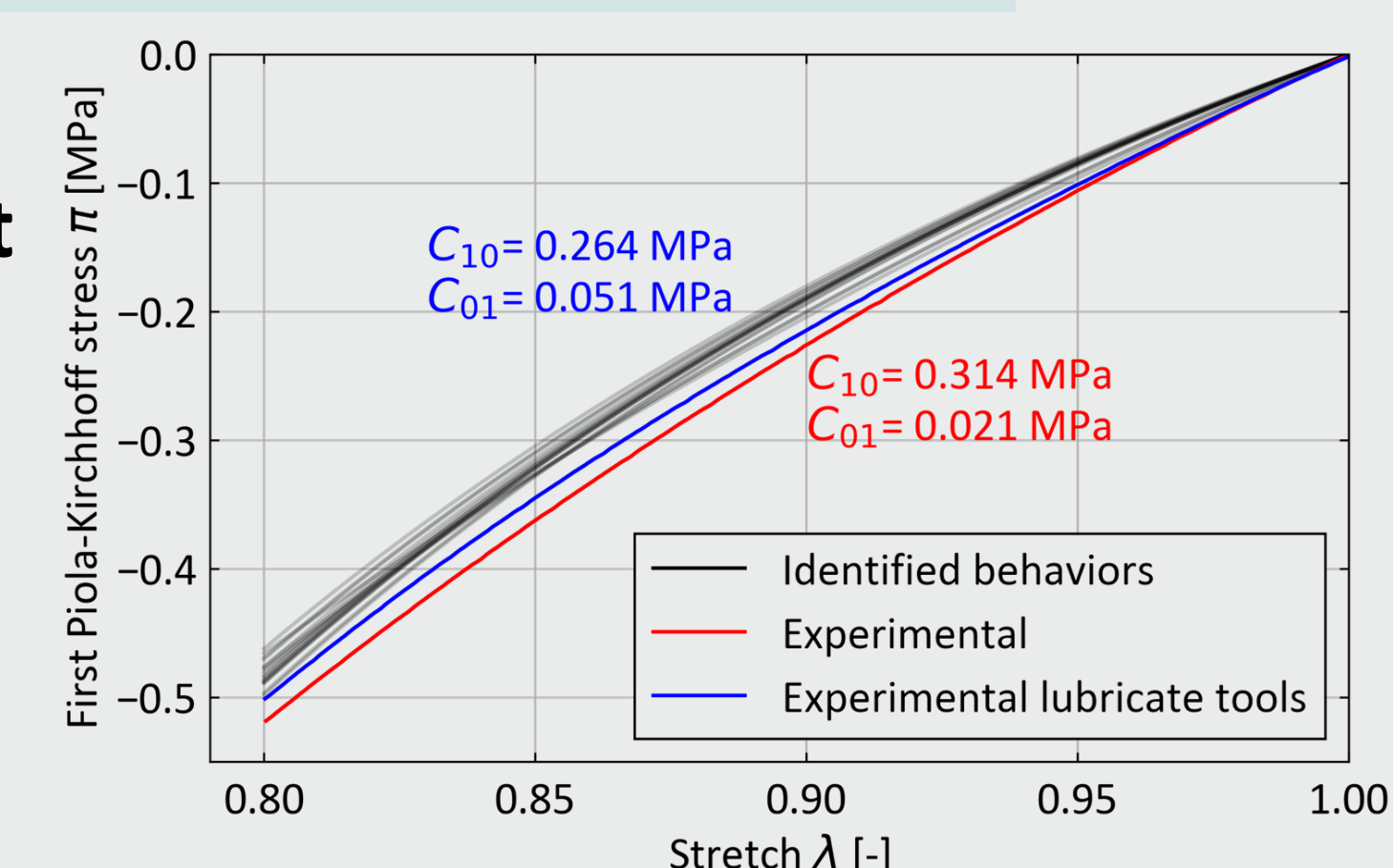
### Experimental issues

Inhomogeneous stress state due to barrel shape effect.

**Solution**: Lubricate tools

Scheme of the barrel shape effect

- Experimental results are compared with theoretical expression of the first Piola-Kirchhoff stress (uniaxial case).  
 $\pi = 2(1 - \lambda^{-3})(\lambda C_{10} + C_{01})$
- Parameters are also identified on macroscopic tests by curve fitting.
- The identified behaviours give lower absolute stress than macroscopic tests. This should be due to barrel shape effect which is minimized by lubrication but not fully eliminated.



Coupling spherical indentation and identification by model reduction allows to characterize the mechanical behaviour of RTV. However, a complete identification of the Mooney-Rivlin constitutive model parameters is not possible. This may be explained by the fact that spherical indentation reaches a low strain level ( $\approx 20\%$ ), so the Mooney-Rivlin model is applied in its low operating limit, where a simpler model such as Neo-Hooke would be adequate. Furthermore, another possible explanation is that spherical indentation does not show any real triaxiality in the stress state. The study of different tip shapes that would increase the triaxiality and the strain level would lead to better identification results. The main perspective of this work is to study visco-hyperelastic material through static and dynamic tests.

[1] Ezzaamari O. Identification des paramètres de lois de comportement hyper-élastiques par nano-indentation et réduction de dimensionnalité [Thèse de doctorat]. Tours; 2022

[2] Treloar LRG. The Physics of Rubber Elasticity. Third Edition. Oxford, New York: Oxford University Press; 2005. 324 p.

[3] Diani J, Gilormini P. Combining the logarithmic strain and the full-network model for a better understanding of the hyperelastic behavior of rubber-like materials. J. Mech. Phys. Solids. 2005;53(11):2579-96.

[4] Bergström J. S - Elasticity/Hyperelasticity. In: Bergström J, editors. Mechanics of Solid Polymers. William Andrew Publishing; 2015. p. 209-307