LTDS
Laboratoire de Tribologie et Dynamique des Systèmes

Real contact area reduction under shear in elastomer/glass contacts : contributing mechanisms for wide range of normal loads

Davy Dalmas

Mariana De Souza & Vito Acito,

Julien Scheibert, S. Dancette, E. Maire, Jakub Lengiewicz and Stanislaw Stupkiewicz

Laboratoire de Tribologie et Dynamique des Systèmes

LTDS UMR 5513

http://ltds.ec-lyon.fr

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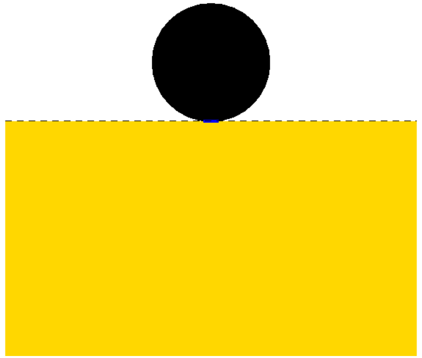
General context: elastomeric contact

Elastomer is a rubber-like polymer with **non-linear elastic** behaviour, **low elastic modulus**, **high friction** and **high adhesion**

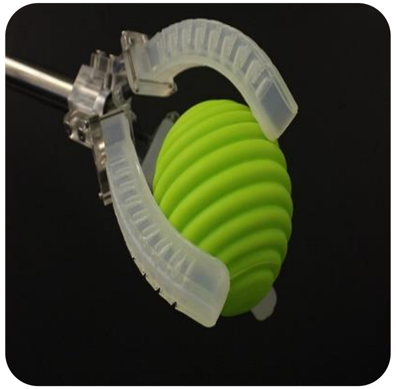


In daily life

Shoe/road

Tyre/road

In technological systems

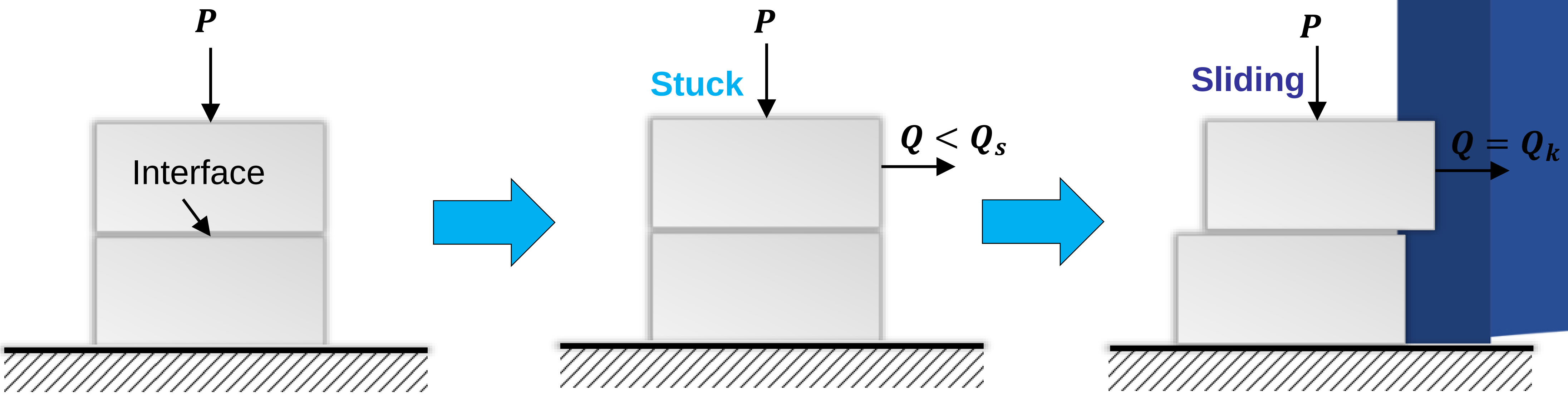


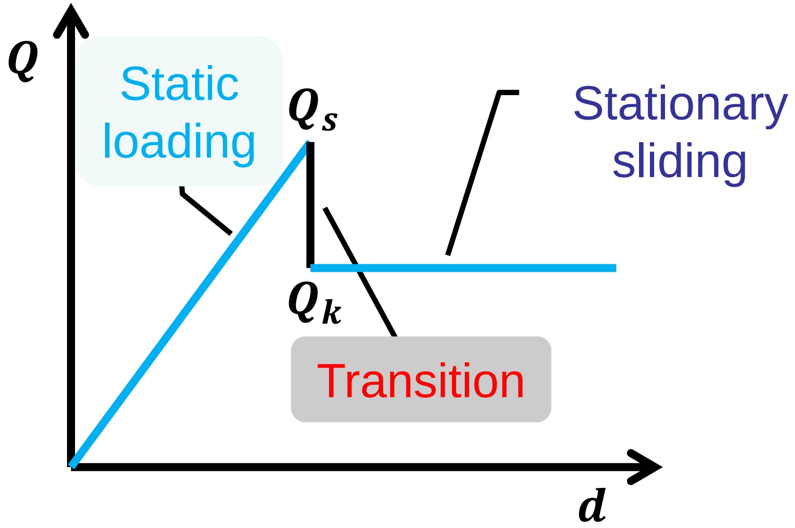
Soft robotics

Haptic system

Sliding onset/transition is a practical issue

General context: onset of sliding surfaces

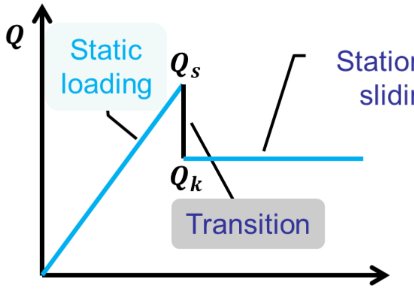


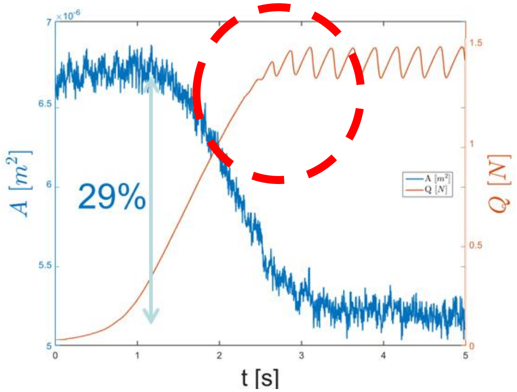


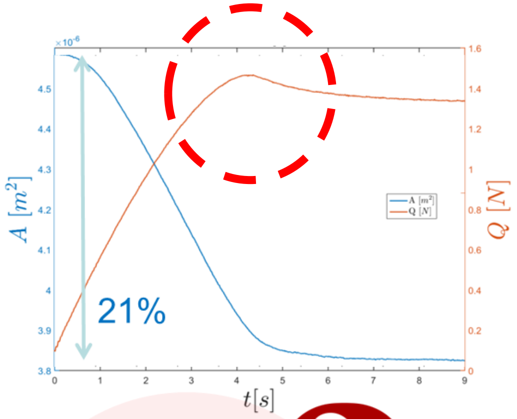
Static Friction	Kinetic Friction
$\mu_s = \dfrac{Q_s}{P}$	$\mu_k = \dfrac{Q_k}{P}$

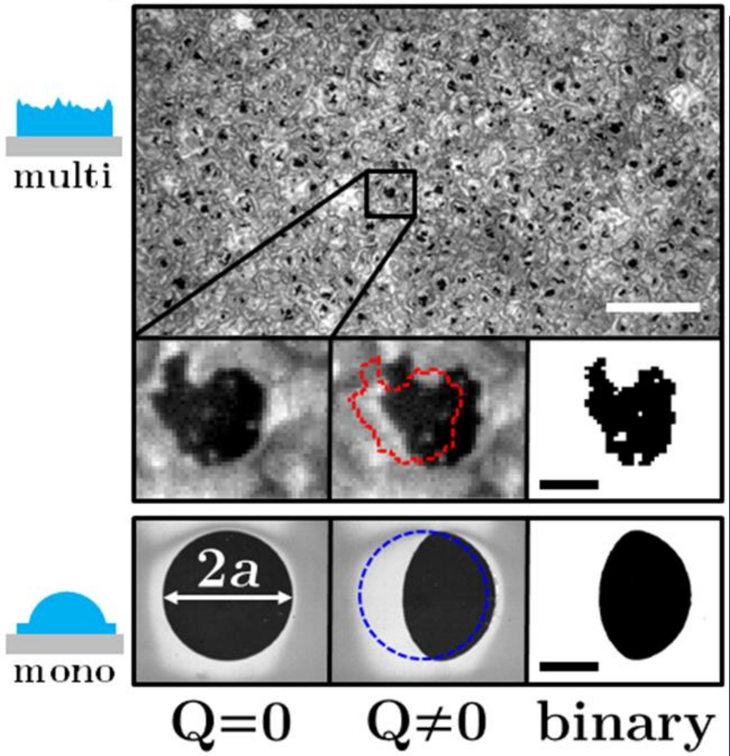
P: Normal load
Q_s: Static tangential force
Q_k: Kinetic tangential force

General context: onset of sliding for elastomers

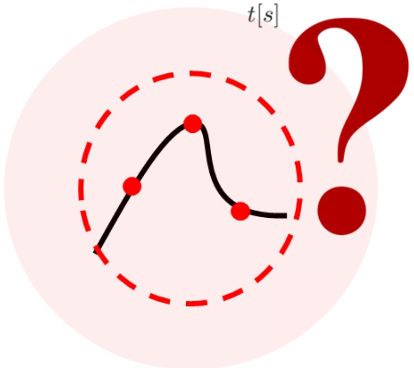








Sliding transition is smooth ?

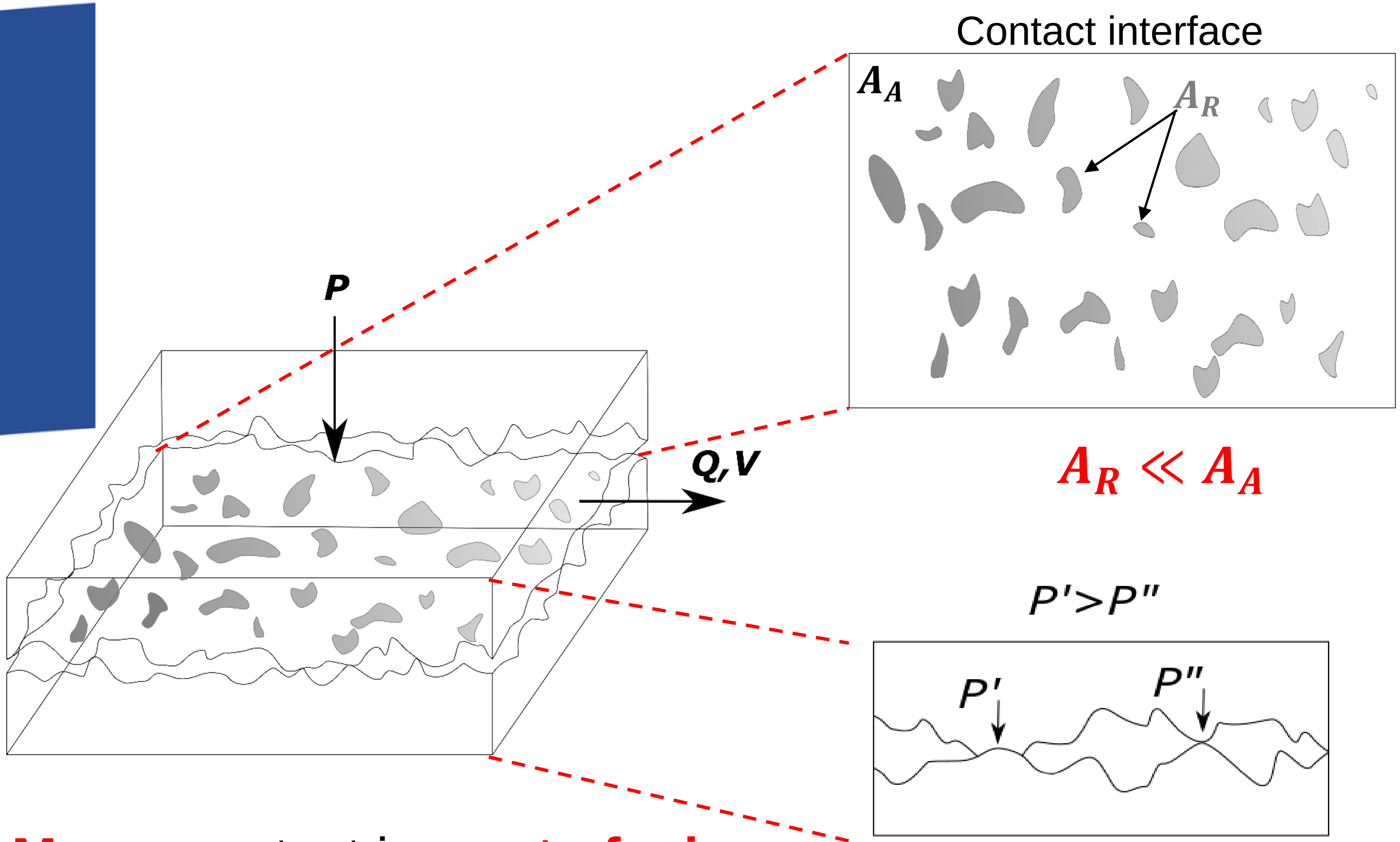


Contact area REDUCES and CHANGES MORPHOLOGICALLY

Sliding onset/transition is a theoretical issue

Savkoor, A. R., & Briggs, G. A. D. (1977), Waters, J. F., & Guduru, P. R. (2010), Sahli, R. (2018), Mergel, J. C. (2020)

Scientific context: real contact area



Lateral section

Macro contact is **a set of micro** contacts

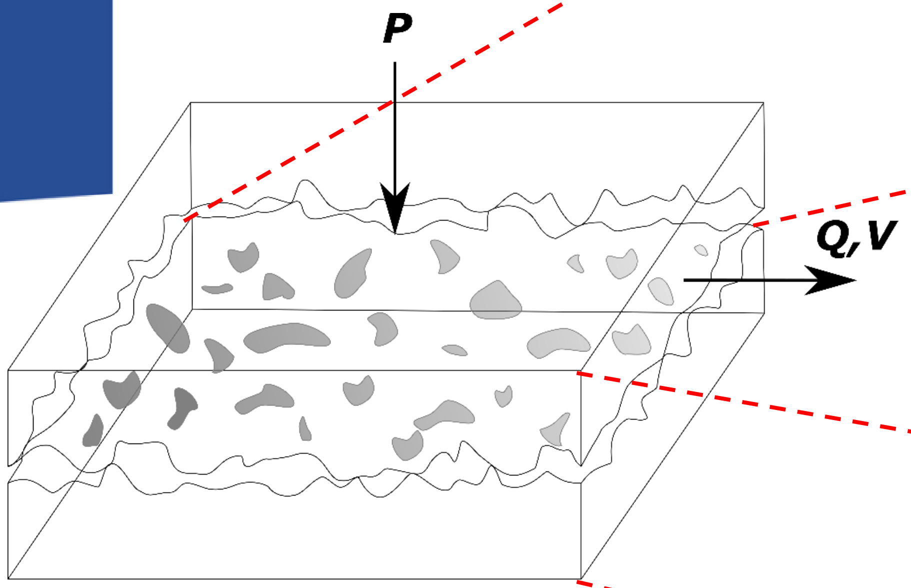
Bowden and Tabor[1]

$$Q_S = \sigma A_R$$

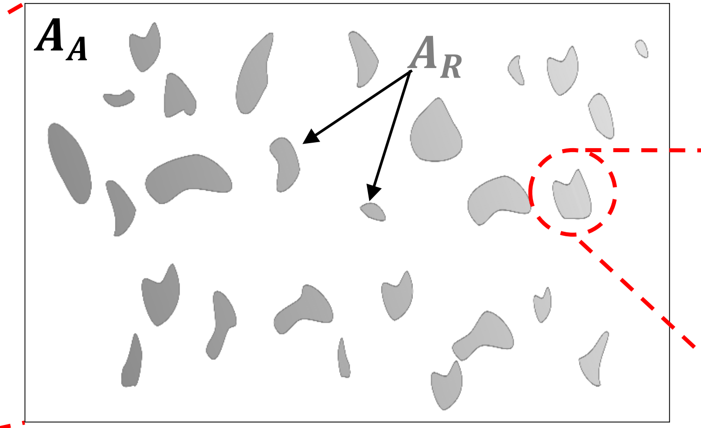
σ: Critical shear strength
Q_S: Static tangential force
A_R: Real contact area at Q_S

[1] F. P. Bowden and D. Tabor. "The Friction and Lubrication of Solids", Oxford University Press, London; England, 1950.

Scientific context: real contact area

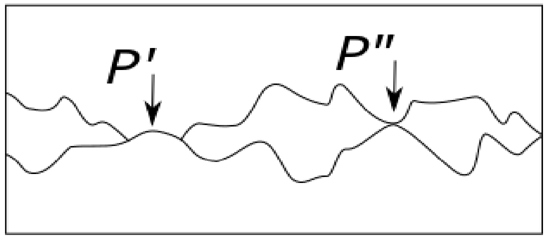


Contact interface



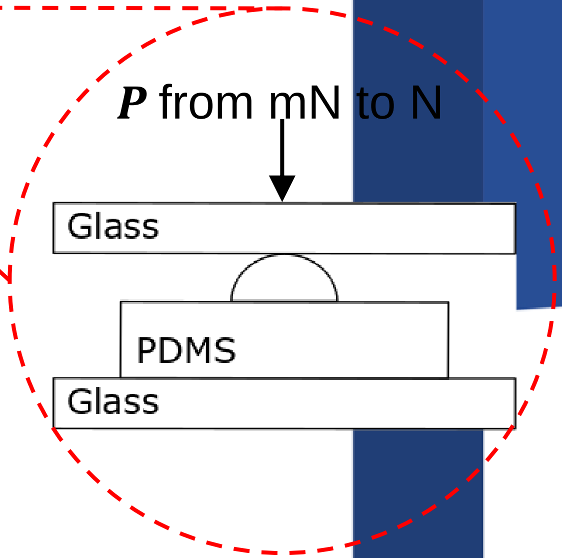
$$A_R \ll A_A$$

$P' > P''$



Lateral section

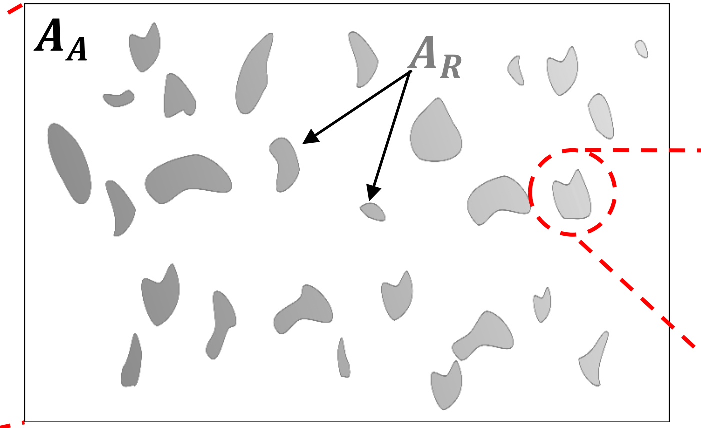
Model sphere/plane



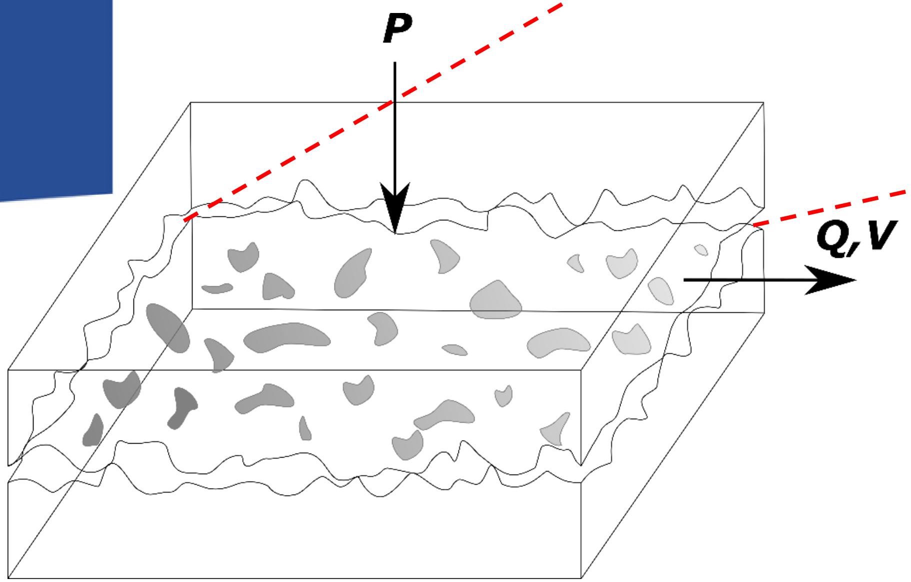
Macro contact is **a set of micro** contacts

Objectives

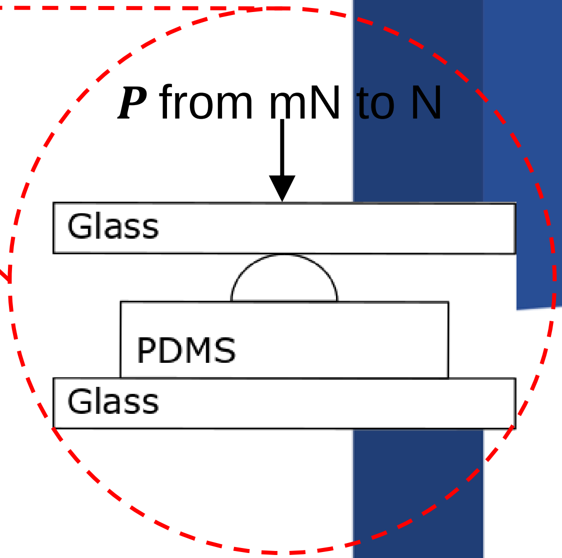
Contact interface



$A_R \ll A_A$

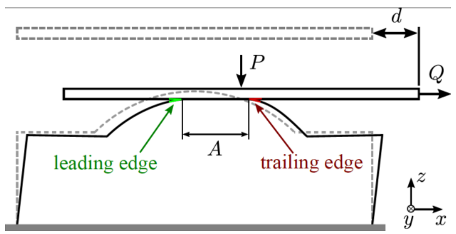


Model sphere/plane

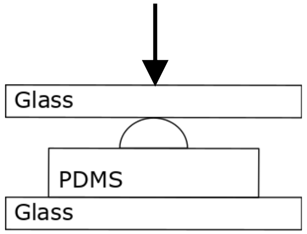


A deepen the understanding of the onset of dry sliding elastomeric by an analyse of a **model sphere/plane interface**

i Fundamental mechanisms

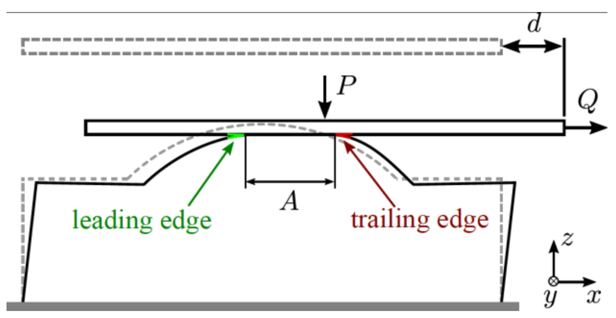


ii Wide range of normal



Objectives and Methods

i Fundamental mechanisms

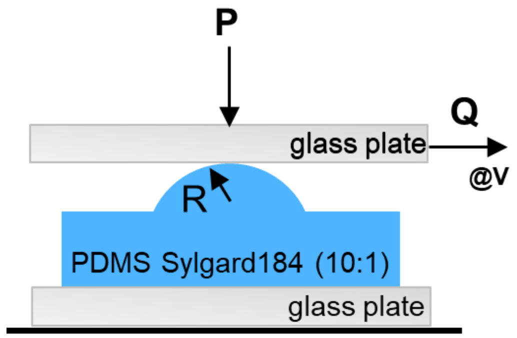


To identify the elementary mechanisms responsible for contact area variation and their relative contributions and to better characterize/localize the sliding transition

Experiments on a laboratory-built tribometer on model interfaces with in-situ visualization :

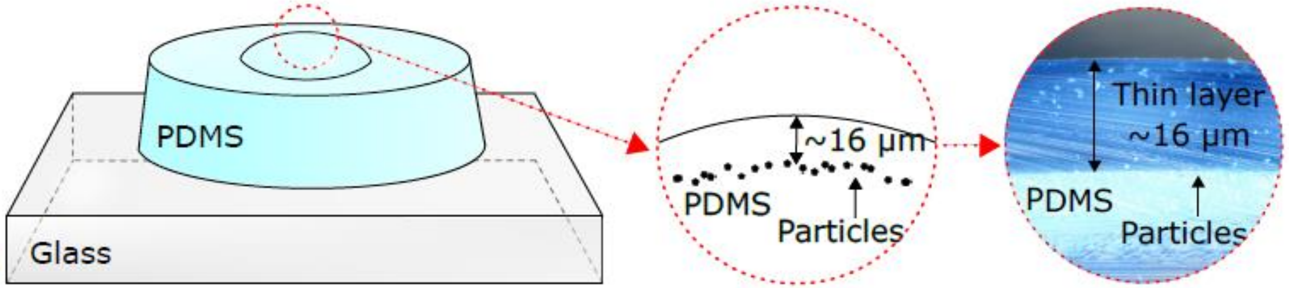
Model interface :

- Sphere/Plate
- PDMS/Glass
- **Dry** friction



Experimental methods: samples

Seeded PDMS (polydimethylsiloxane) spheres

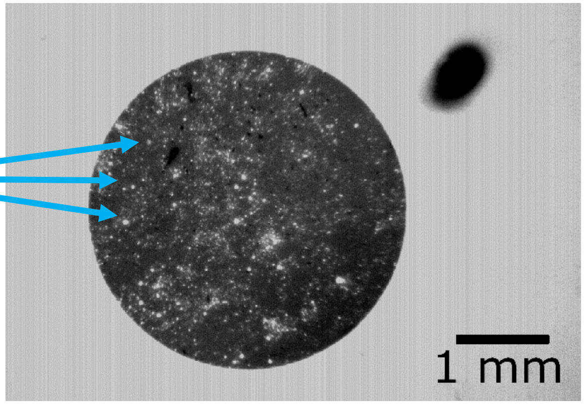


PDMS/glass dry interface

Incorporation of particles close to the PDMS sphere surface

Silver particles:

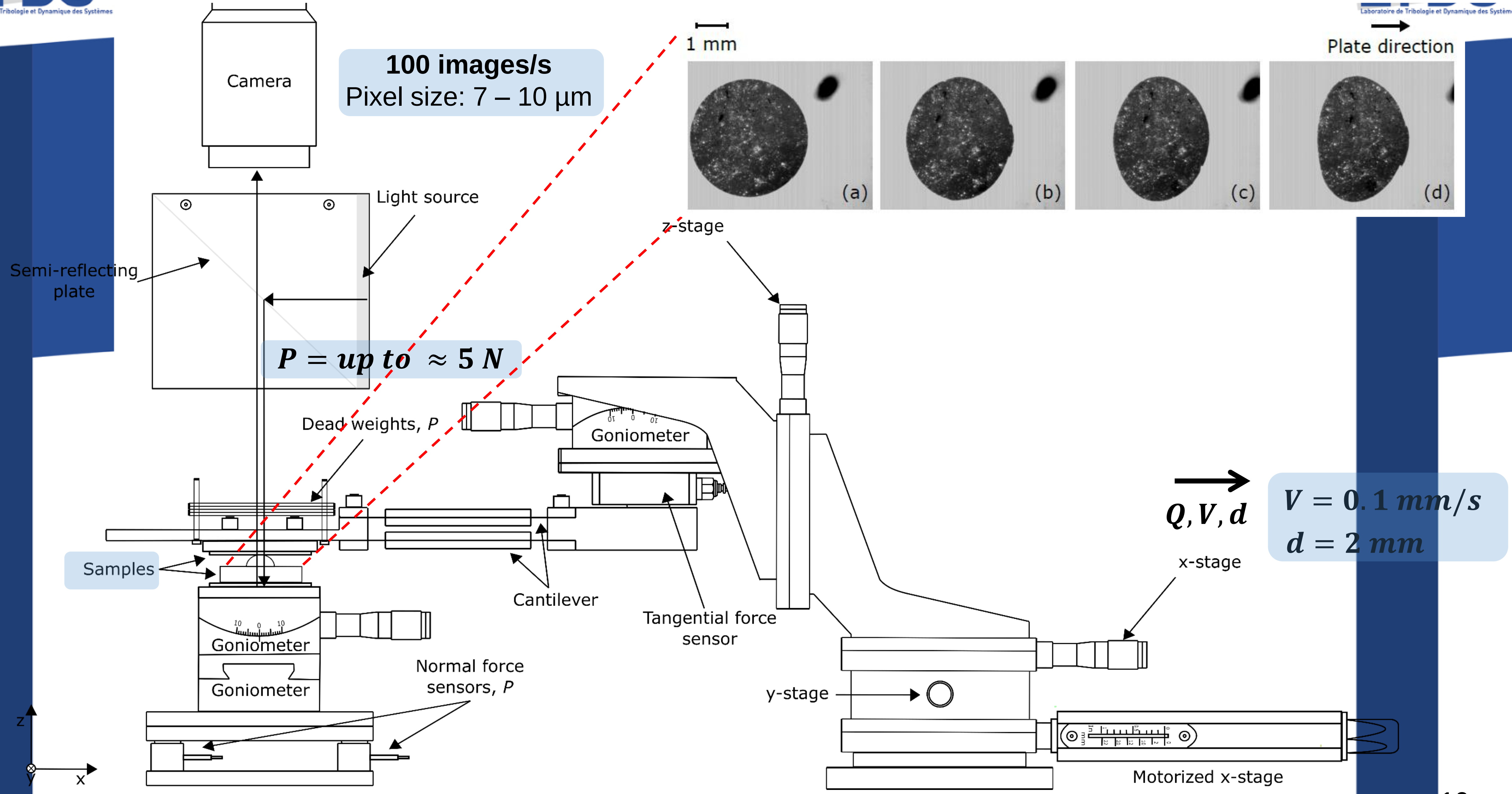
- Located close to the sphere surface
- Visible by the camera
- Thin layer of particles



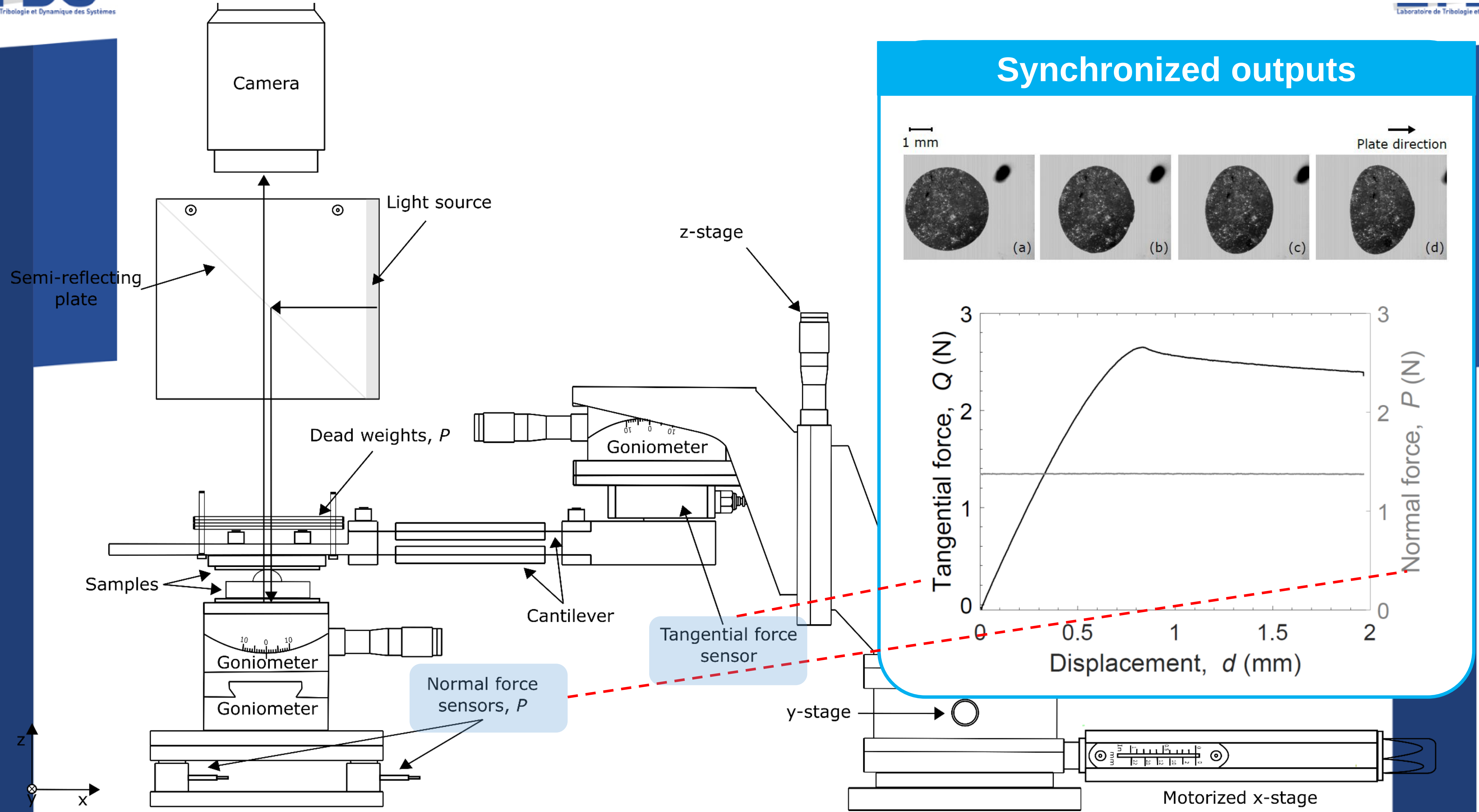
*Only the tracers at the vertical of the contact regions are visible

The **bright spots** present in the images were used as **tracers of the contact evolution**

Experimental methods: optomechanical instrument

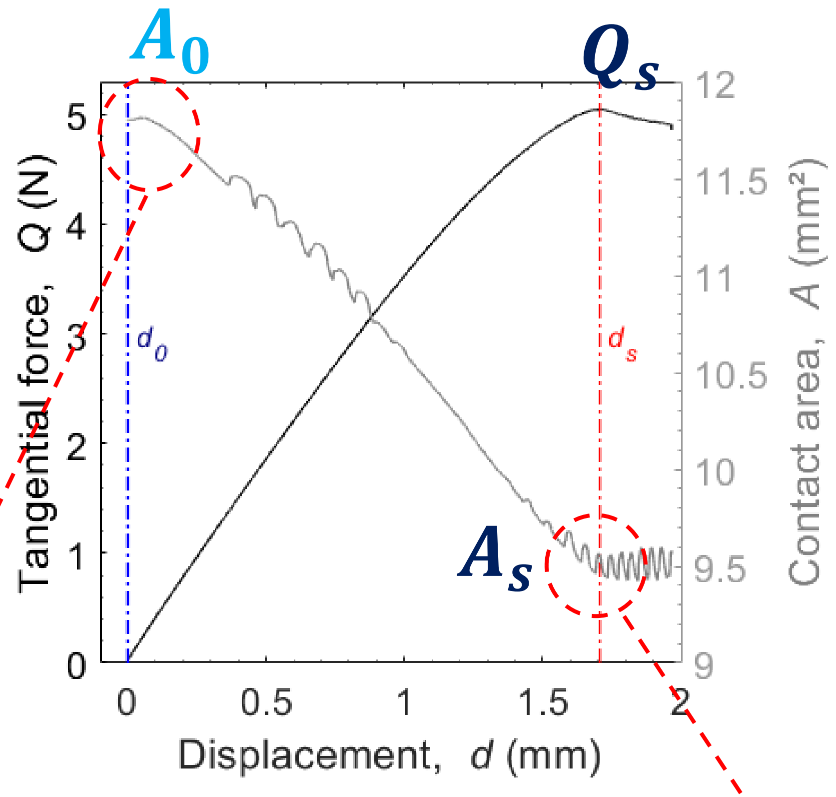


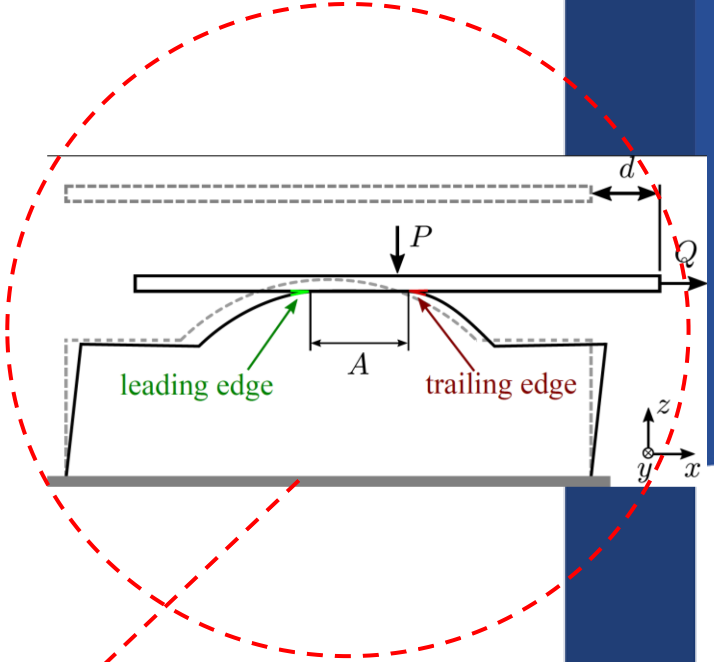
Experimental methods: optomechanical instrument

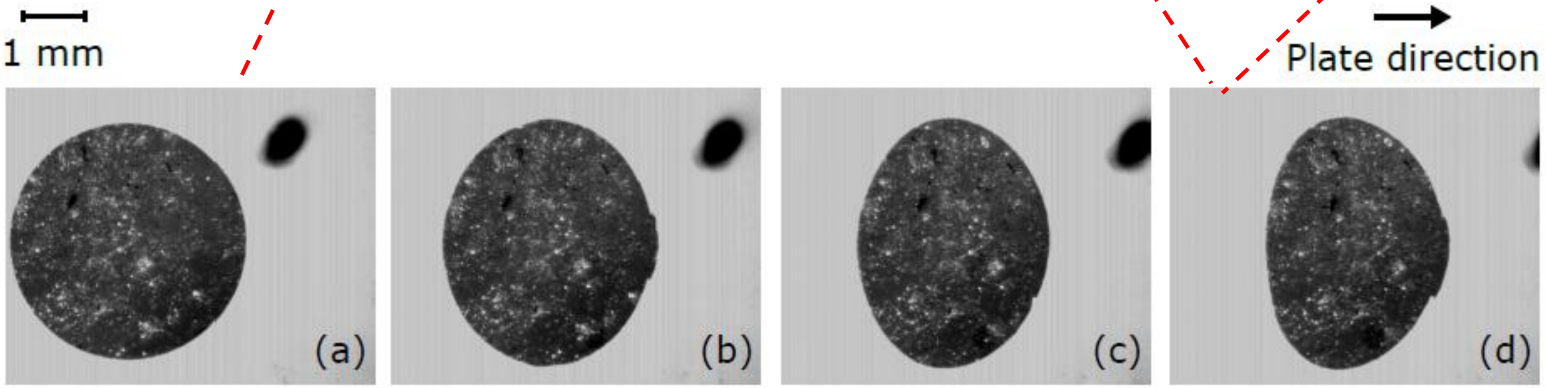


Results : in-situ contact observation

$P = 1.85\ N$
$V = 0.1\ mm/s$
$d = 2\ mm$



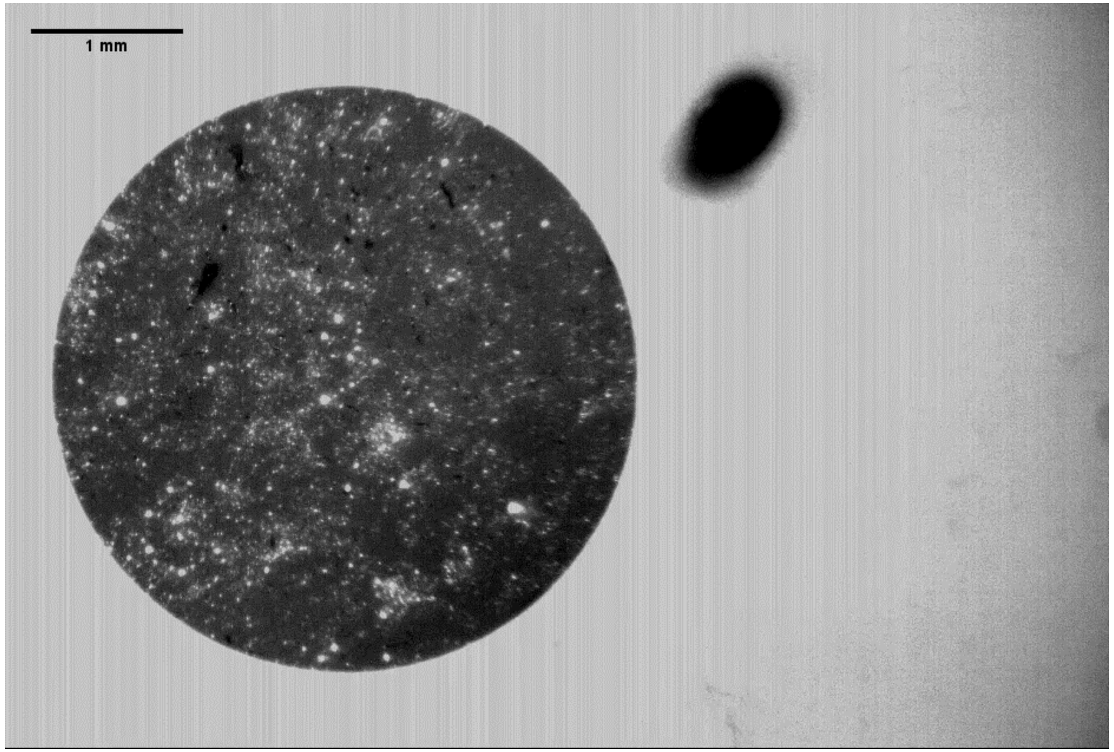




$Q = 0$ $Q = Q_s$

J. Lengiewicz, M. de Souza et al., Journal of the Mechanics and Physics of Solids 143 (2020), p. 104056.

Results : in-situ contact observation



Q →

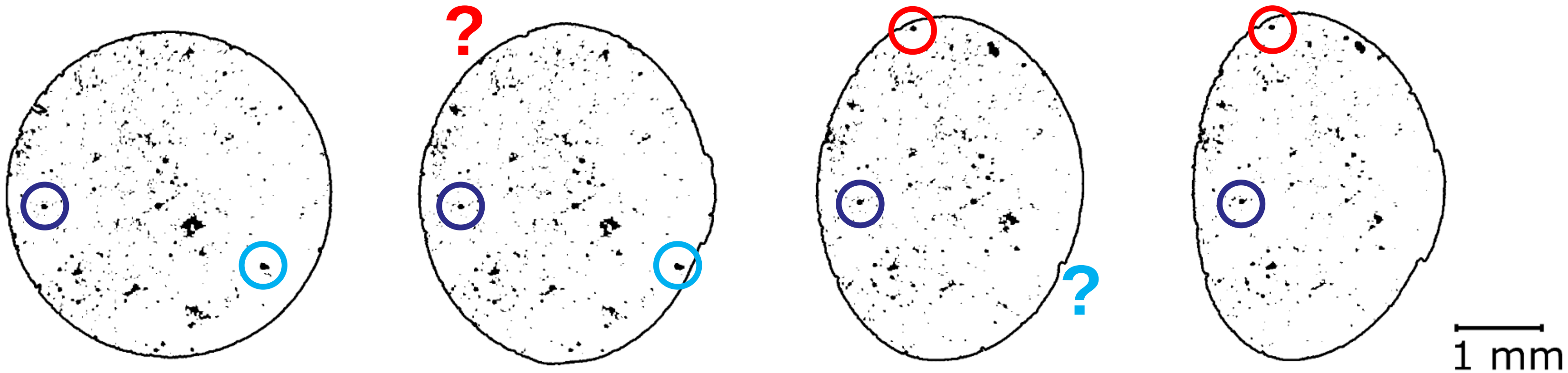
PIV (Particle Image Velocimetry) type procedure → Evolution of tracers x- and y-positions for each image/time-step

3 sets :

Disappear

Appear

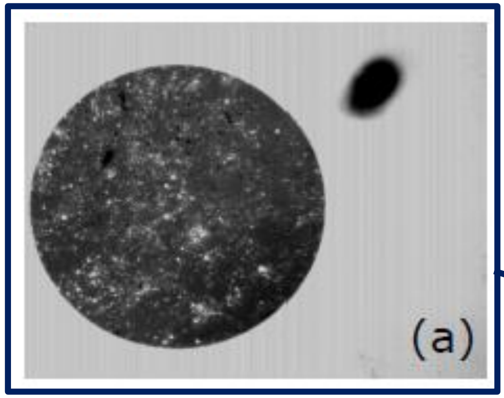
Ever-present



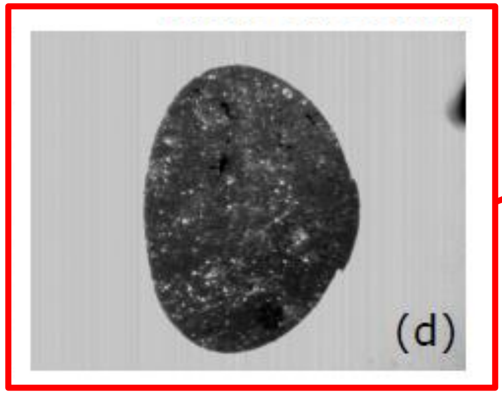
J. Lengiewicz, M. de Souza et al., Journal of the Mechanics and Physics of Solids 143 (2020), p. 104056.

Mechanisms of contact area reduction

$\boldsymbol{d_0}$



$\boldsymbol{d_s}$



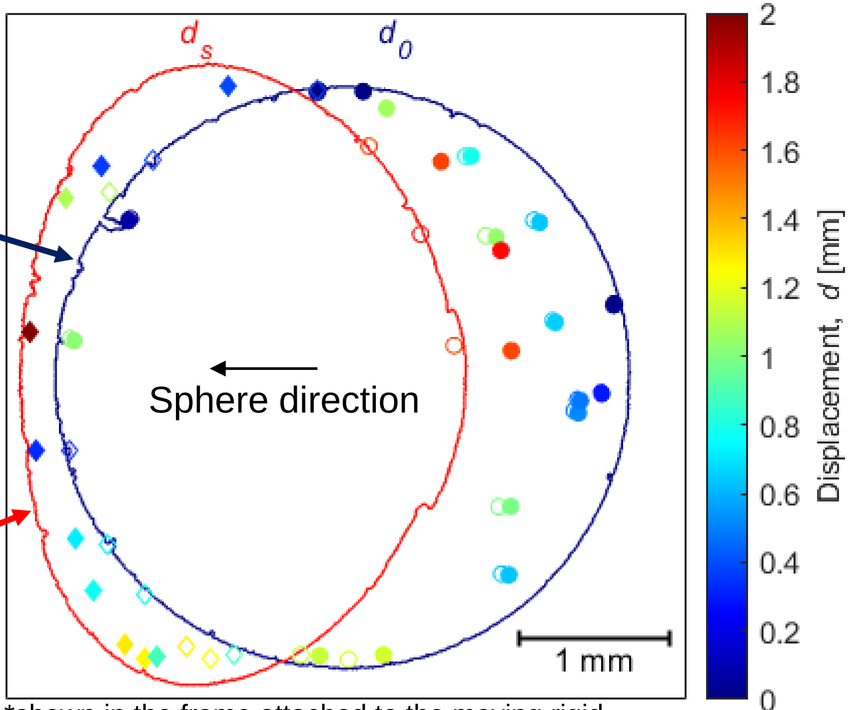
$P = 1.85\ N$
$V = 0.1\ mm/s$
$d = 2\ mm$

Leading edge (left)

◇ : Contact laying

Trailing edge (right)

○: Contact lifting



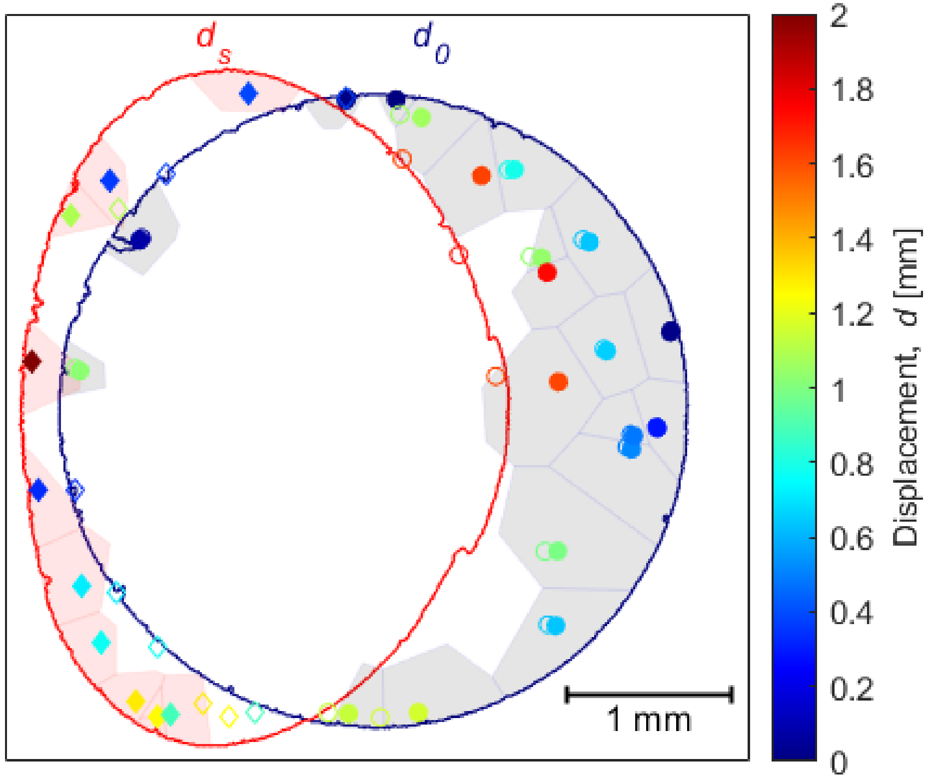
*shown in the frame attached to the moving rigid plate

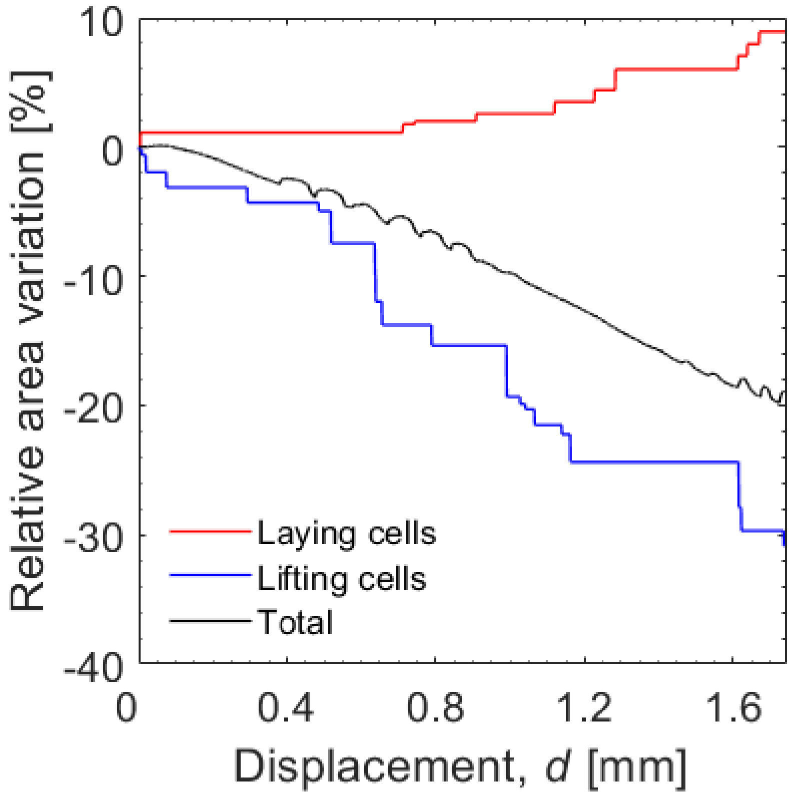
J. Lengiewicz, M. de Souza et al., Journal of the Mechanics and Physics of Solids 143 (2020), p. 104056.

Mechanisms of contact area reduction

Graphical approach to **quantify** the **contribution of contact lifting and laying**

Voronoi tessellation based method:





Contact LIFTING is the main contribution

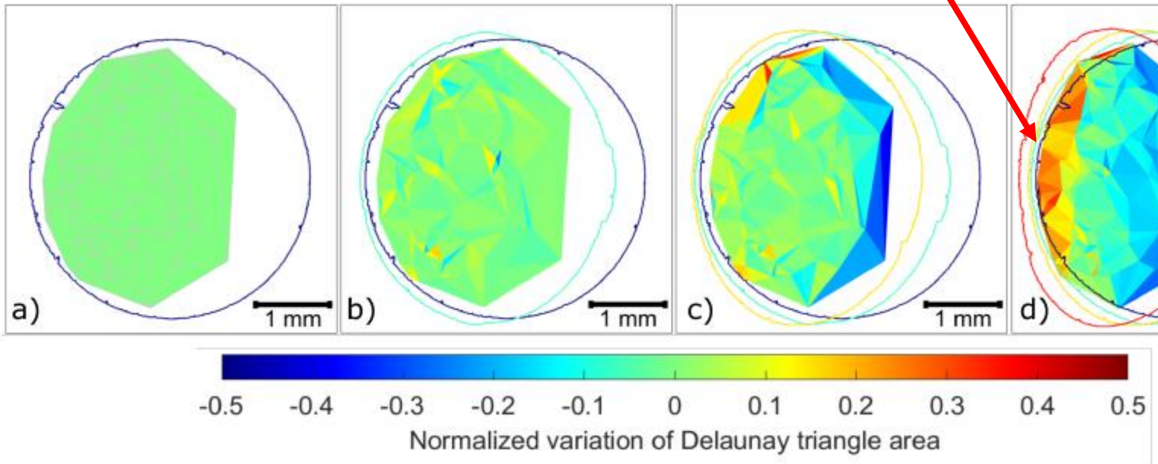
J. Lengiewicz, M. de Souza et al., Journal of the Mechanics and Physics of Solids 143 (2020), p. 104056.

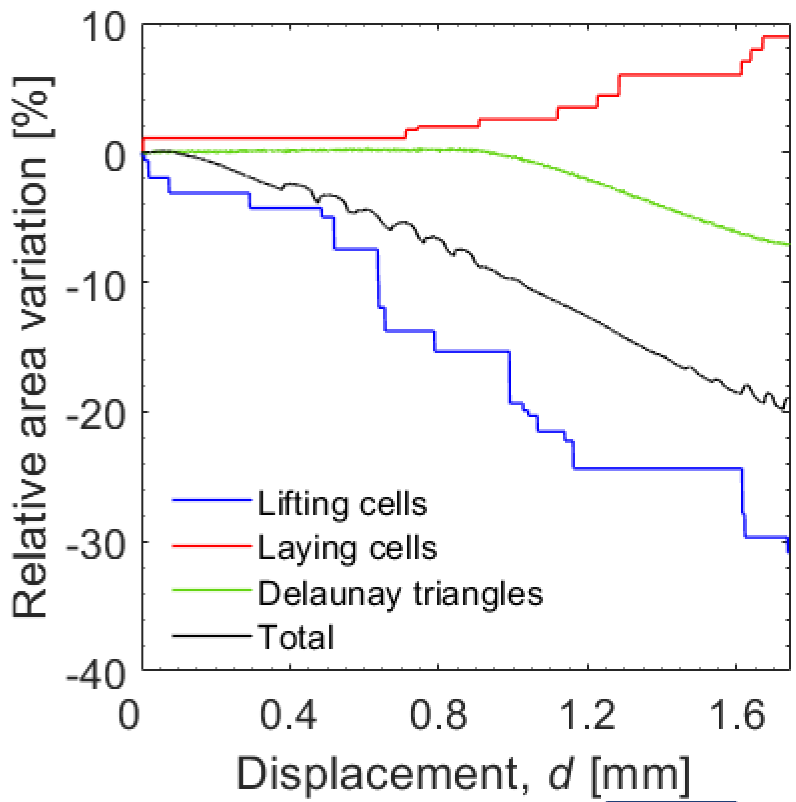
Mechanisms of contact area reduction

Delaunay triangulation based method on the ever present tracers:

In-plane deformation in the real contact zone :

- Compression at the leading edge
- Traction at the trailing edge



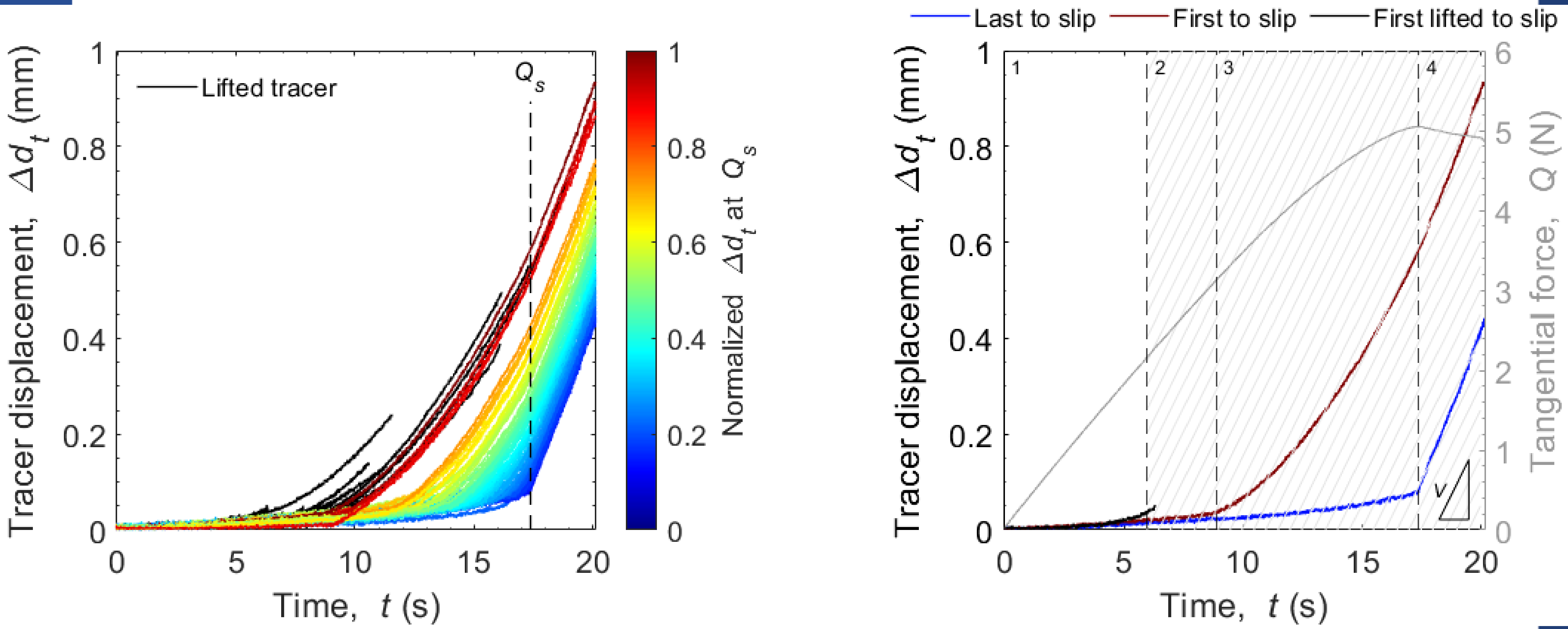


Three mechanisms : **(i) Contact LIFTING (main contribution), (ii) Contact Laying and (iii) in plane deformation.**

J. Lengiewicz, M. de Souza et al., Journal of the Mechanics and Physics of Solids 143 (2020), p. 104056.

Sliding transition : partial slip

Evolution of the tracers displacement

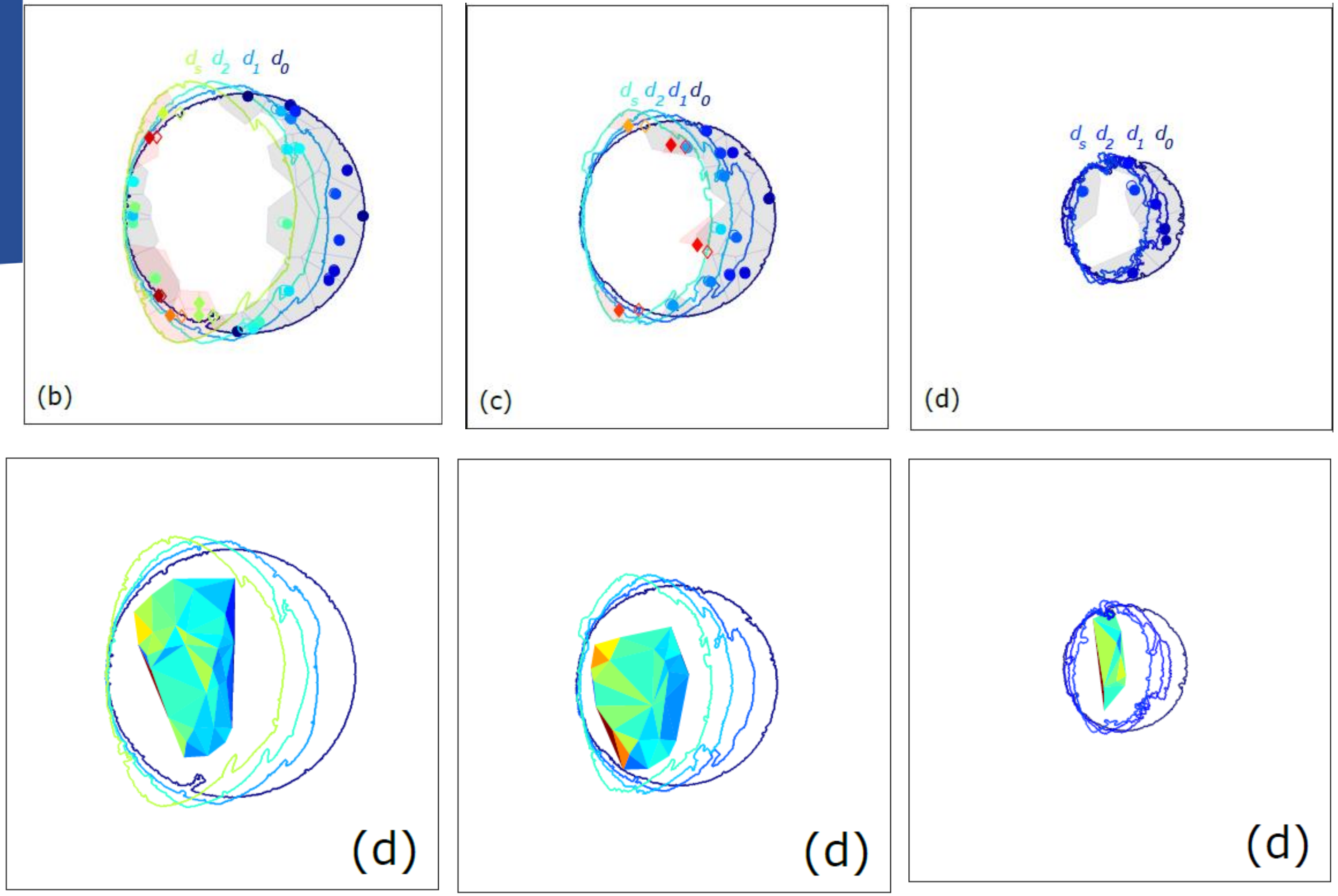


Three successive stages: (1-2) a **stuck stage**
(2-4) a **partial slip stage**
(4-5) a classical **steady-state sliding**

Mechanisms of shear-induced contact area reduction

Different normal forces

P = 0.54 N　　*P* = 0.25 N　　*P* = 0.05 N

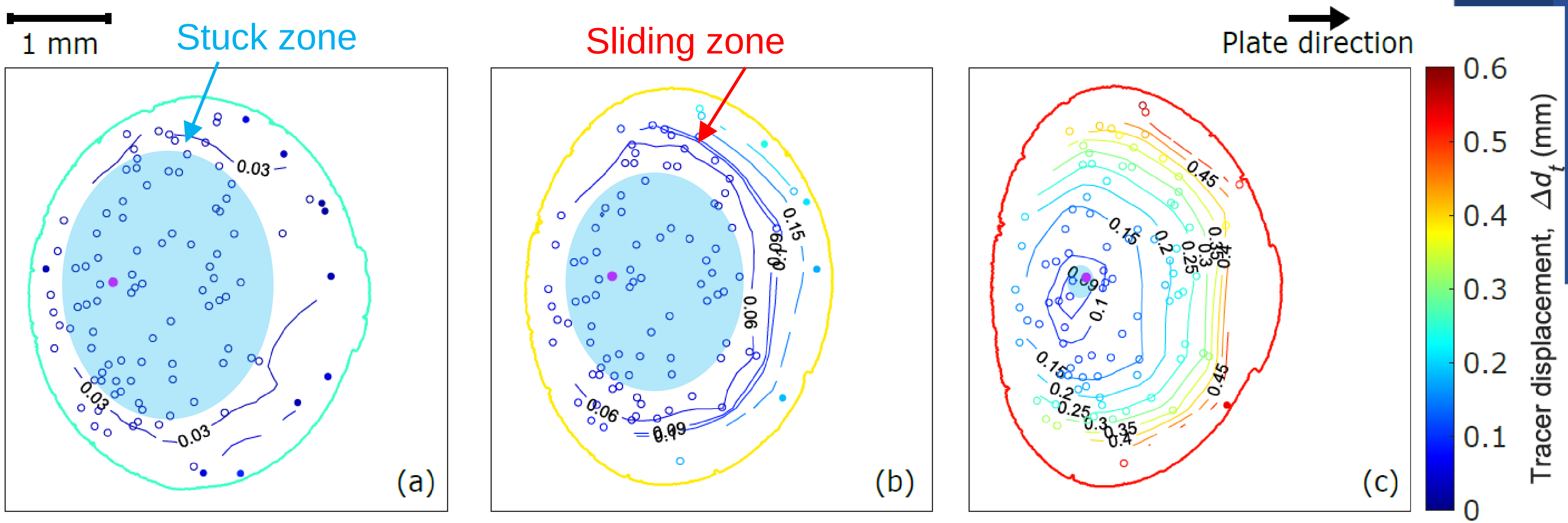


- same mechanisms
- different contributions

- low particle resolution

Sliding transition : micro slip front

Spatial distribution of the tracers displacement



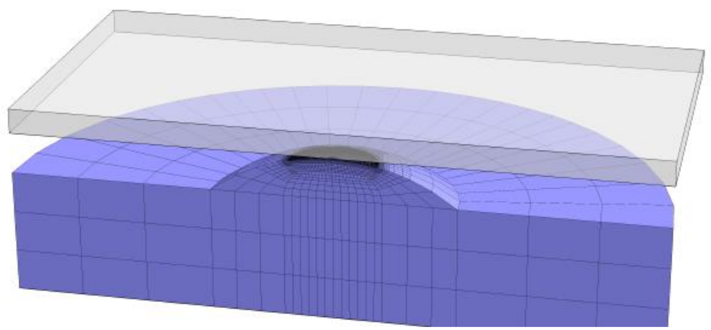
Last tracer to slip

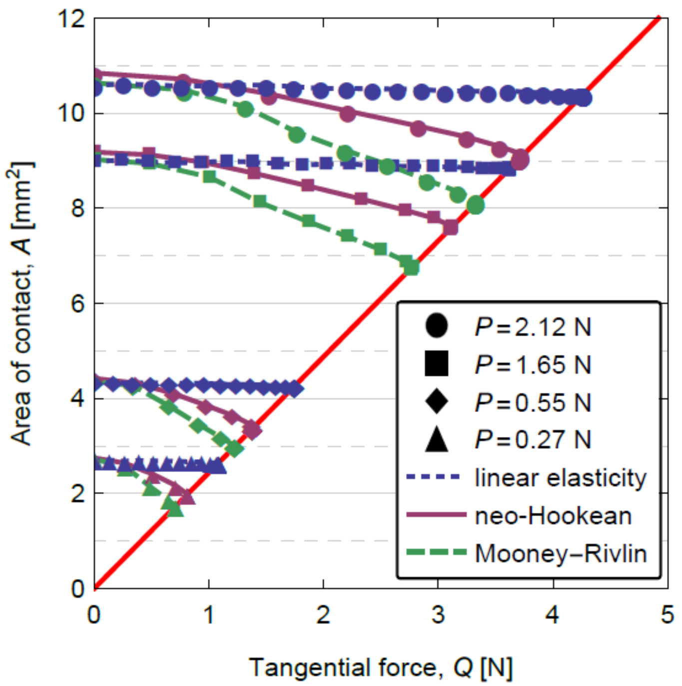
A micro-slip front moves from the contact periphery inward the contact region as shear increases and is responsible for the in plane deformation

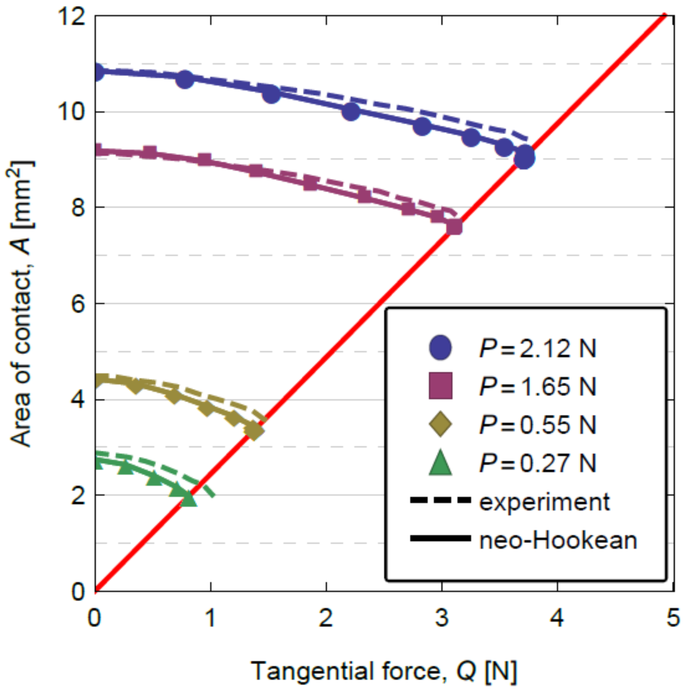
Finite element approach

Collaboration with **Jakub Lengiewicz**[1] et **Stanislaw Stupkiewicz**[1]

Hypothesis that the reduction of the contact area under shearing is an effect of deformation due to interfacial friction







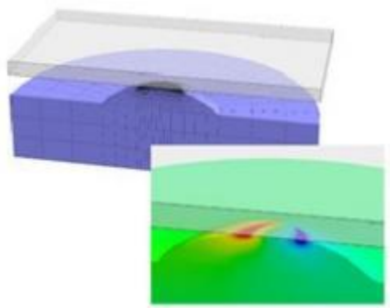
Elastic modulus
Sample geometry
Interfacial shear strength
Non adhesive contact
Non linear elasticity

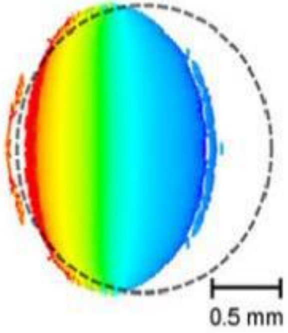
No ajustable parameter

[1] Institute of Fundamental Technological Research (IPPT), Polish Academy of Sciences.

Experiment vs Simulation

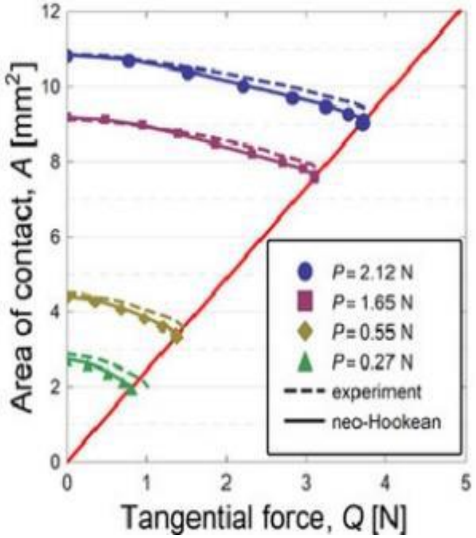
Finite-deformation model

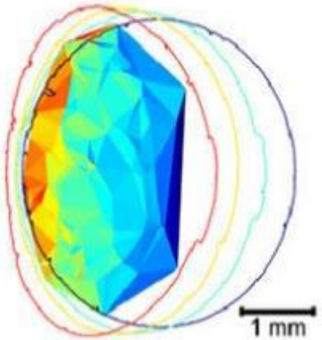




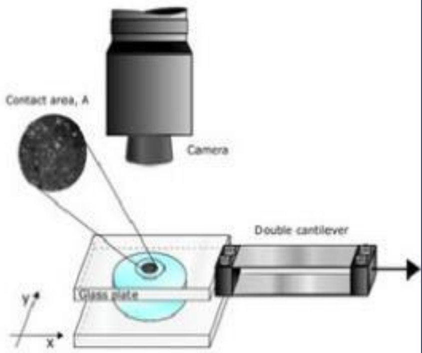
non-adhesive contact
non-linear elasticity

Shear-induced contact area reduction





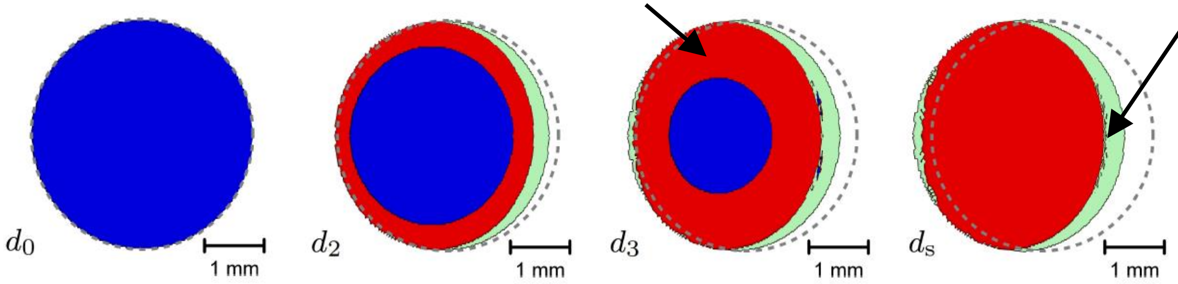
Full-field measurement



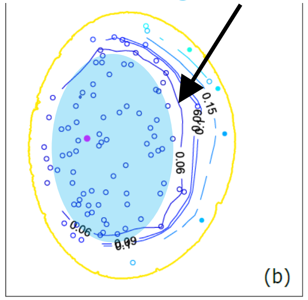
particle tracking

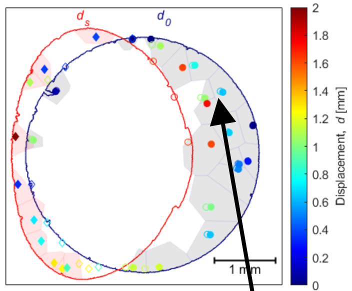
Sliding zone

Contact lifting



Sliding zone





Contact lifting

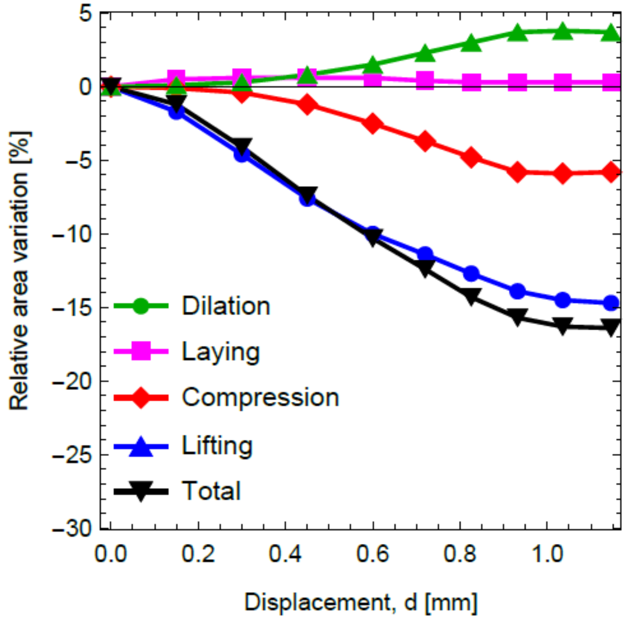
Qualitative validation of the elementary mechanisms by comparison with finite deformation model

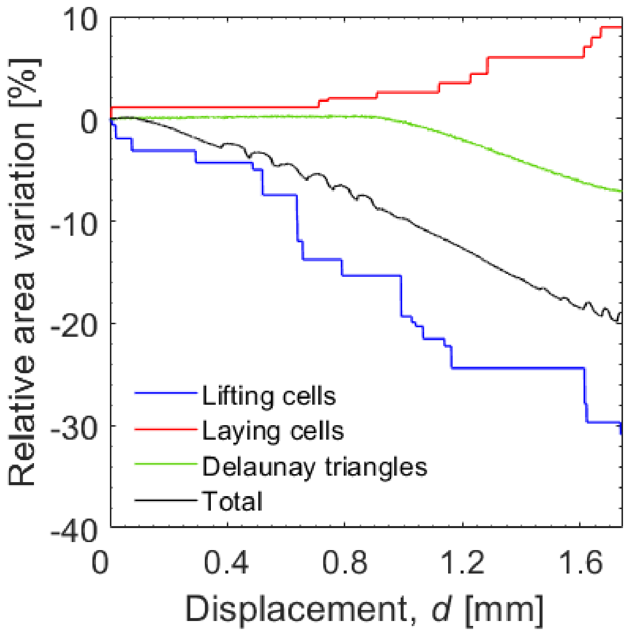
[1] J. Lengiewicz, M. de Souza et al., Journal of the Mechanics and Physics of Solids 143 (2020), p. 104056.

Experiment vs Simulation

Quantitative validation of the elementary mechanisms contribution

Simulation





Experiment

Take home message

Contact area reduction under shear, at large load, is:

- **due to contact lifting/laying and in-plane deformation (partial slip front)**
- **an effect of large deformation due to high interfacial shear strength**