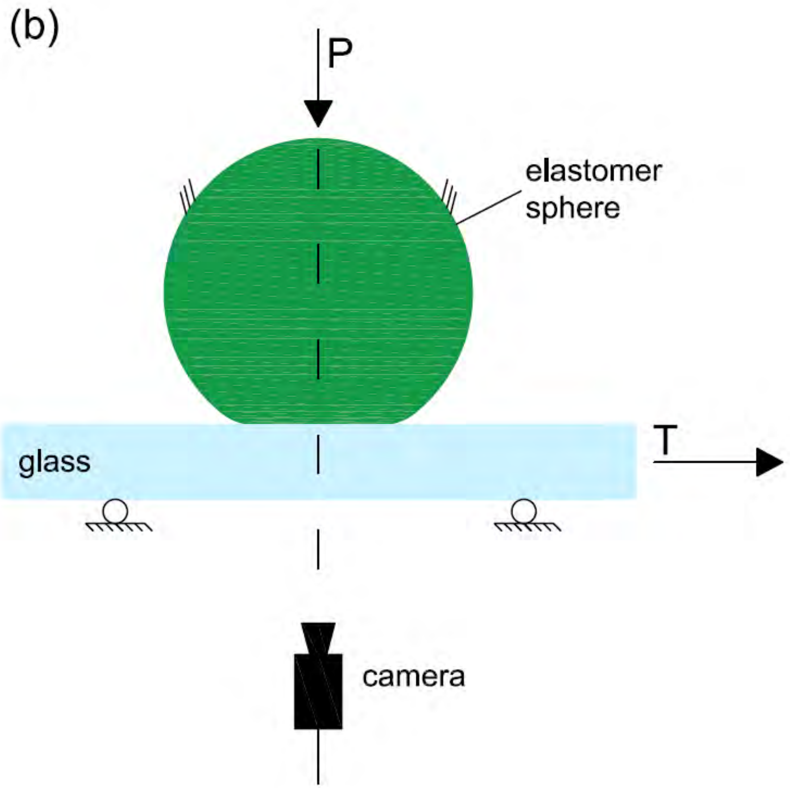
Le couplage entre adhésion et friction

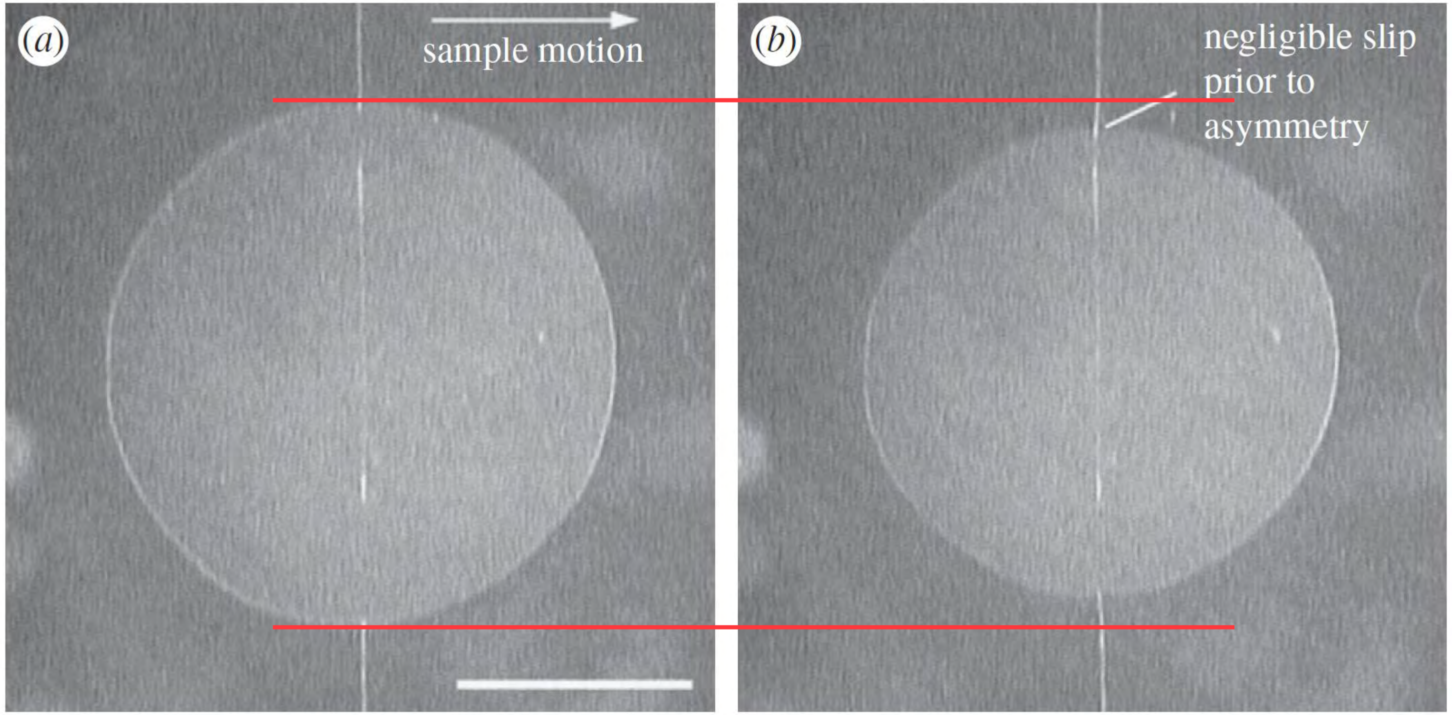
Etienne Barthel

Sciences et Ingénierie de la Matière Molle

CNRS / ESPCI / Sorbonne Université

Coupling adhesion and friction

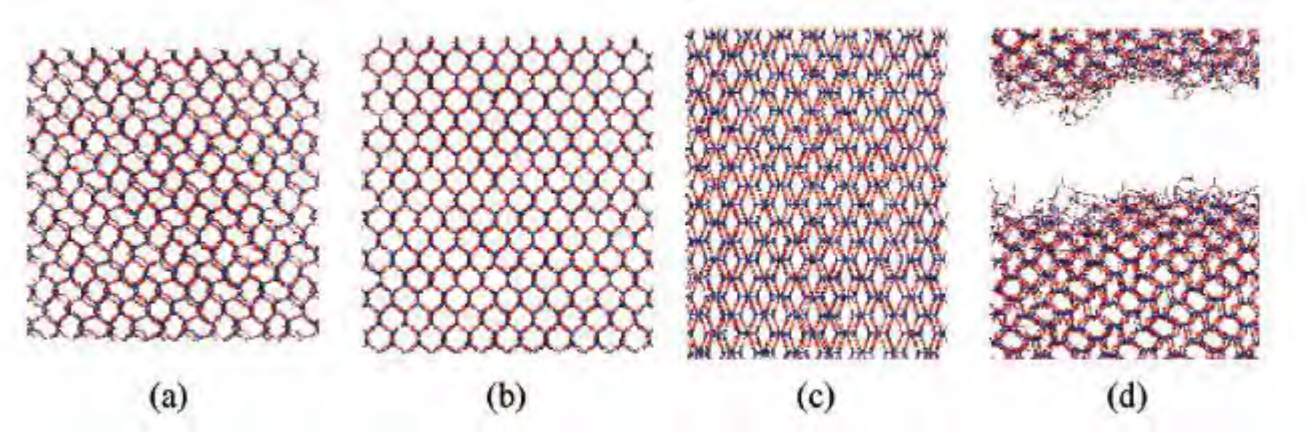


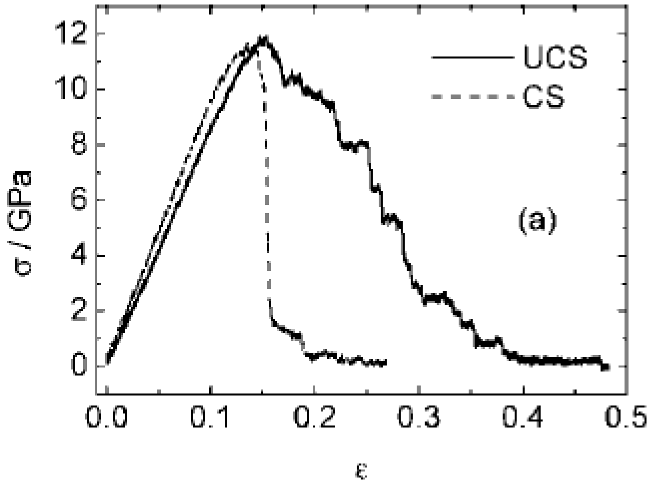


Papangelo 2019

Waters 2010

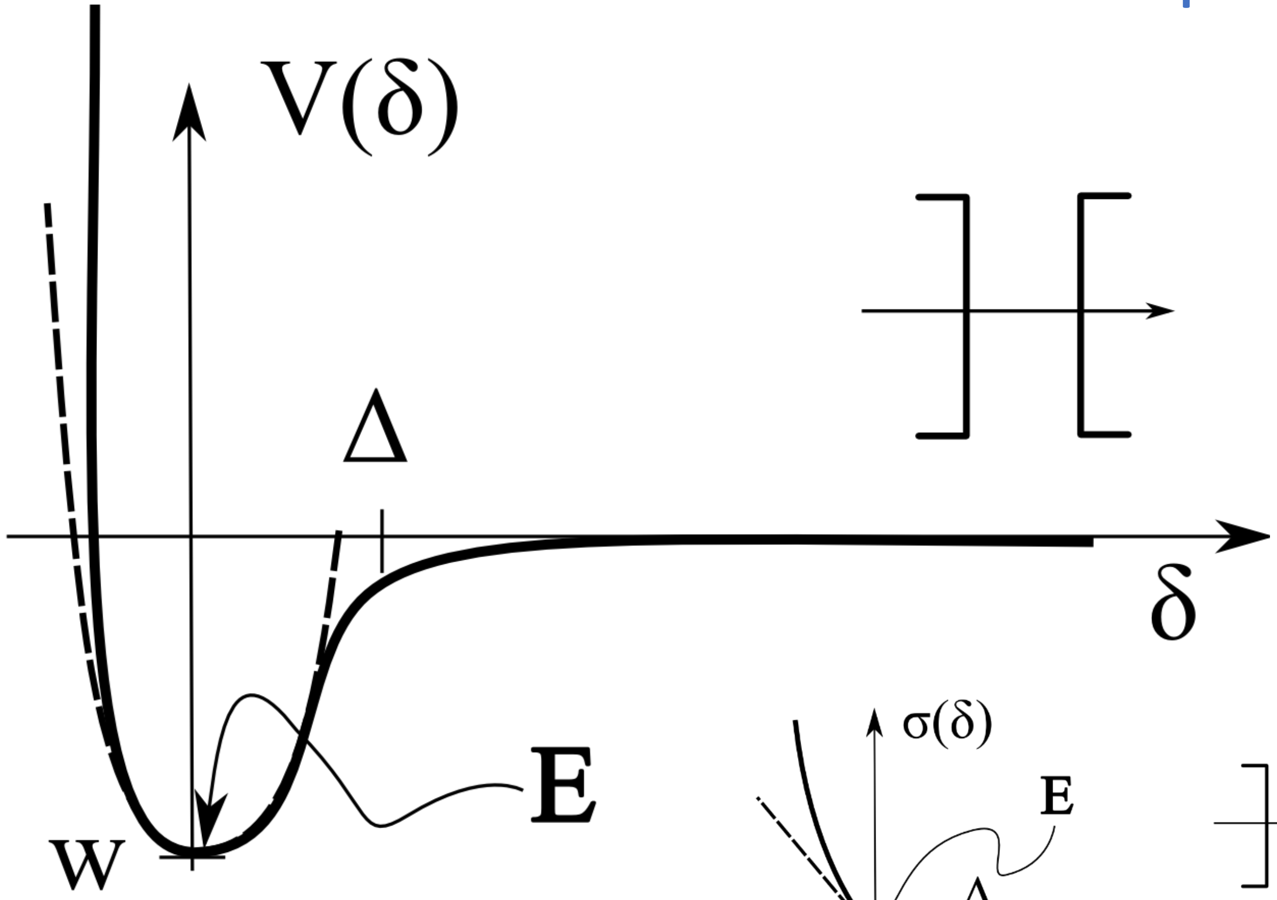
Material rupture – homogeneous ?

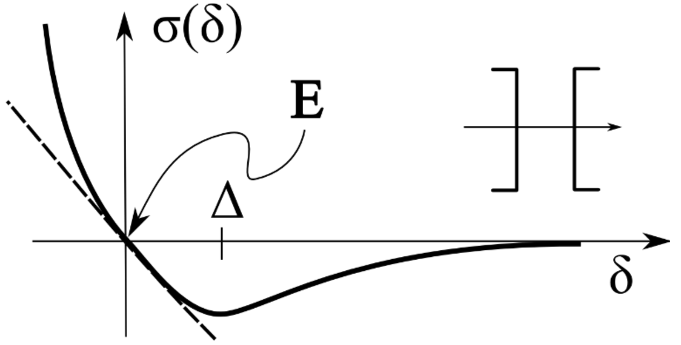


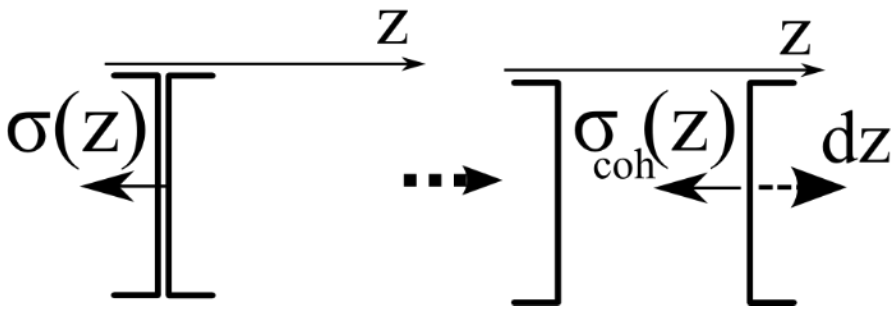


Pedone 2008

Surface separation







$$\sigma_{theo} \simeq \sqrt{\frac{2Ew}{\Delta}}$$

E. Barthel "Rupture, Fracture and Size Issues“ in *Mechanics of Nano-Objects*, O. Thomas, A. Ponchet and S. Forrest eds. 2011.

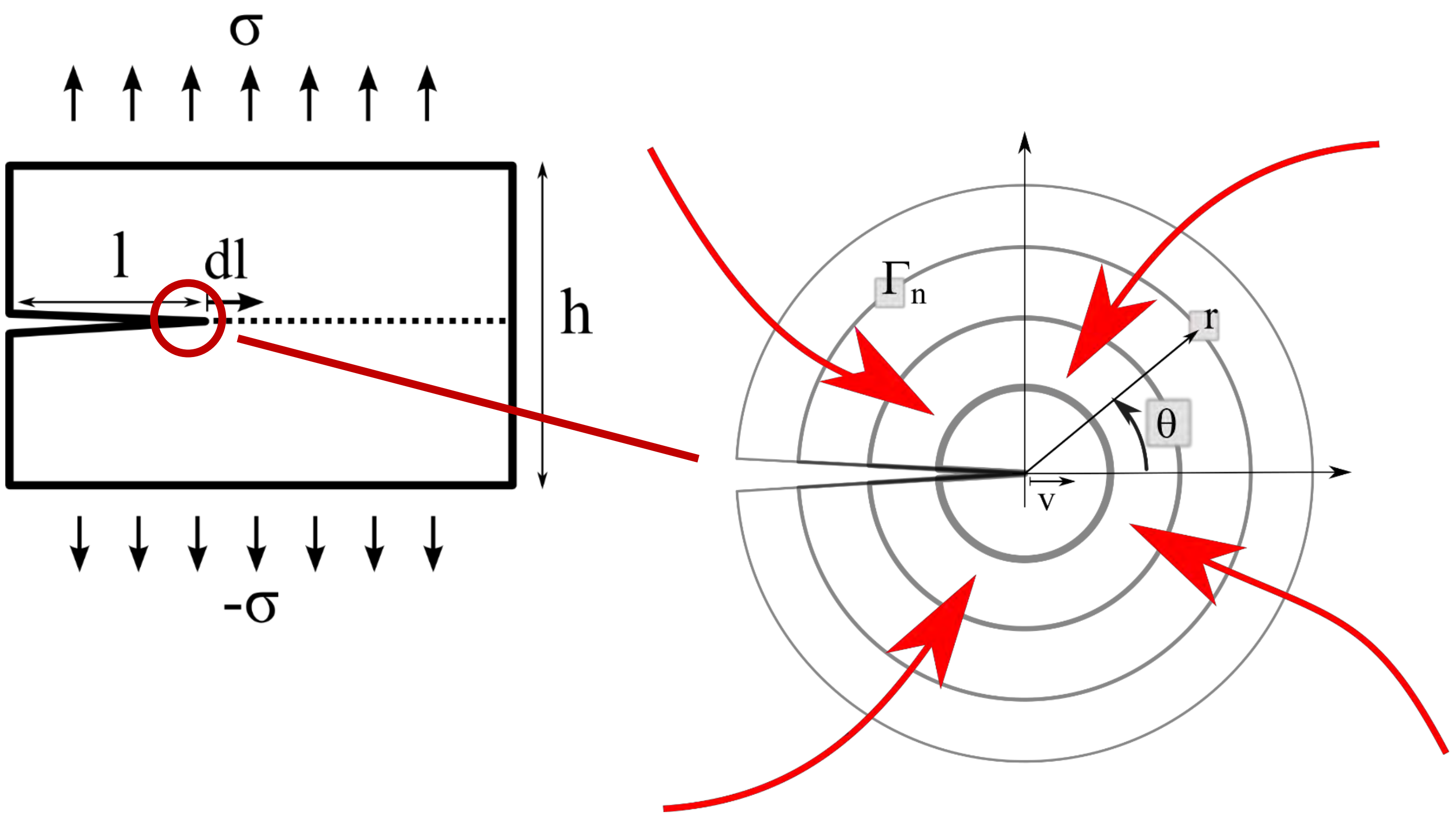
Typical stress

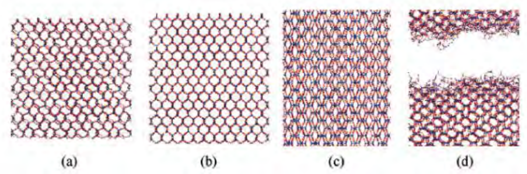
$$
\begin{aligned}
w &\simeq 1\ \mathrm{Jm}^{-2} \\
\Delta &\simeq 0.2\ \mathrm{nm} \\
E &\simeq 100\ \mathrm{GPa} \\
\sigma_{theo} &\simeq 30\ \mathrm{GPa}
\end{aligned}
$$

or 100 tons $= 10^6$ N on 1×1 cm^2 !!!

E. Barthel "Rupture, Fracture and Size Issues“ in *Mechanics of Nano-Objects*, O. Thomas, A. Ponchet and S. Forrest eds. 2011.

Rupture is heterogeneous – energy flow





K : stress intensity factor

$$\sigma \propto \frac{K}{r^{1/2}}$$

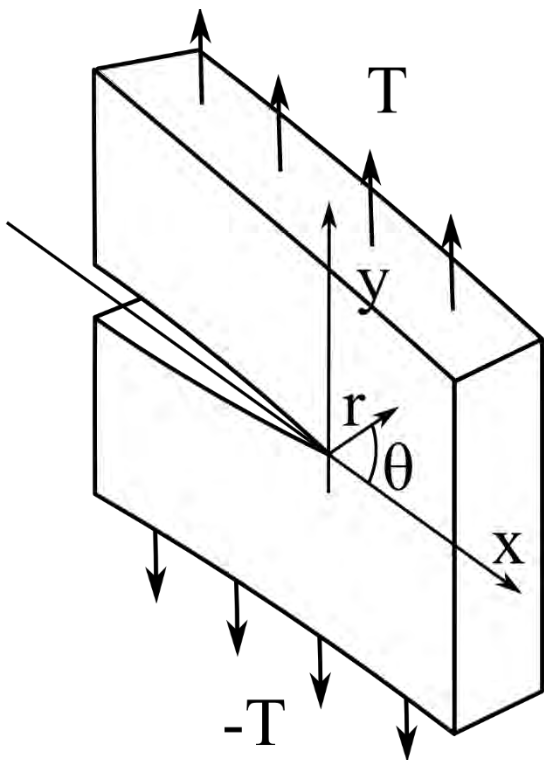
w : adhesion/cohesion energy

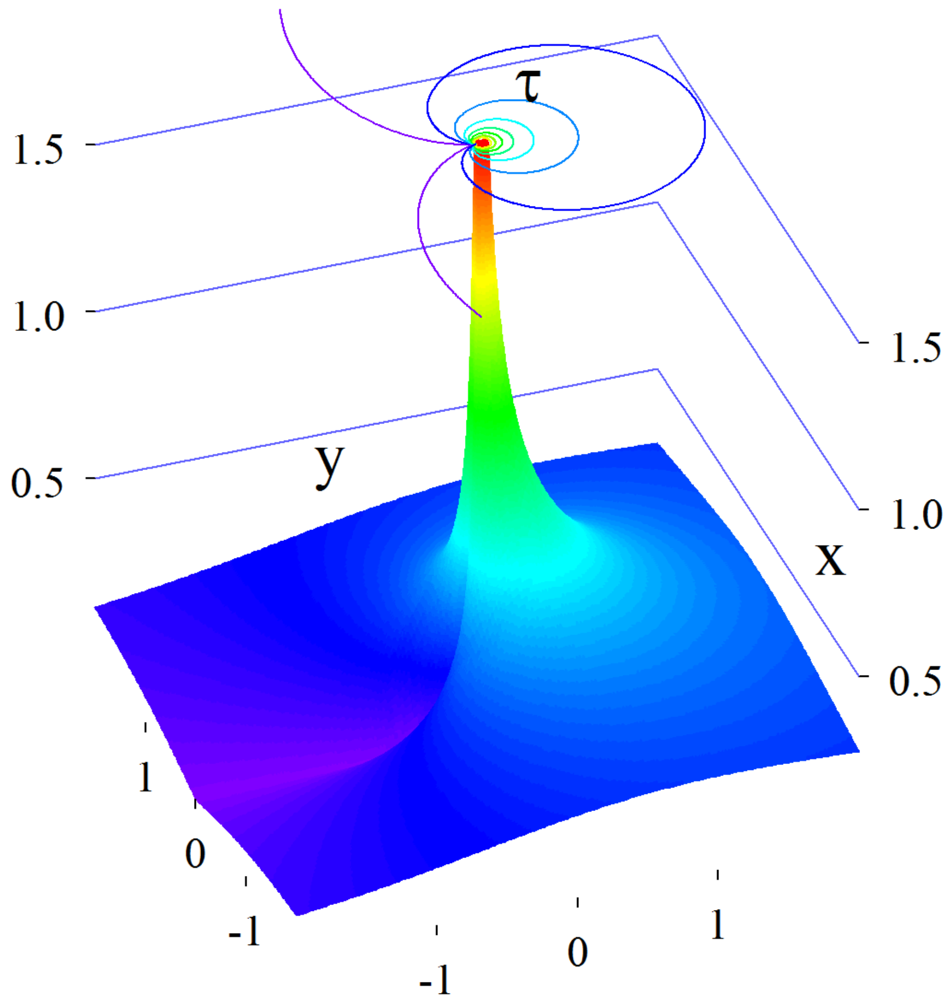
$$w = \frac{K^2}{E}$$

$$\mathcal{E} = \frac{\sigma^2}{E}$$

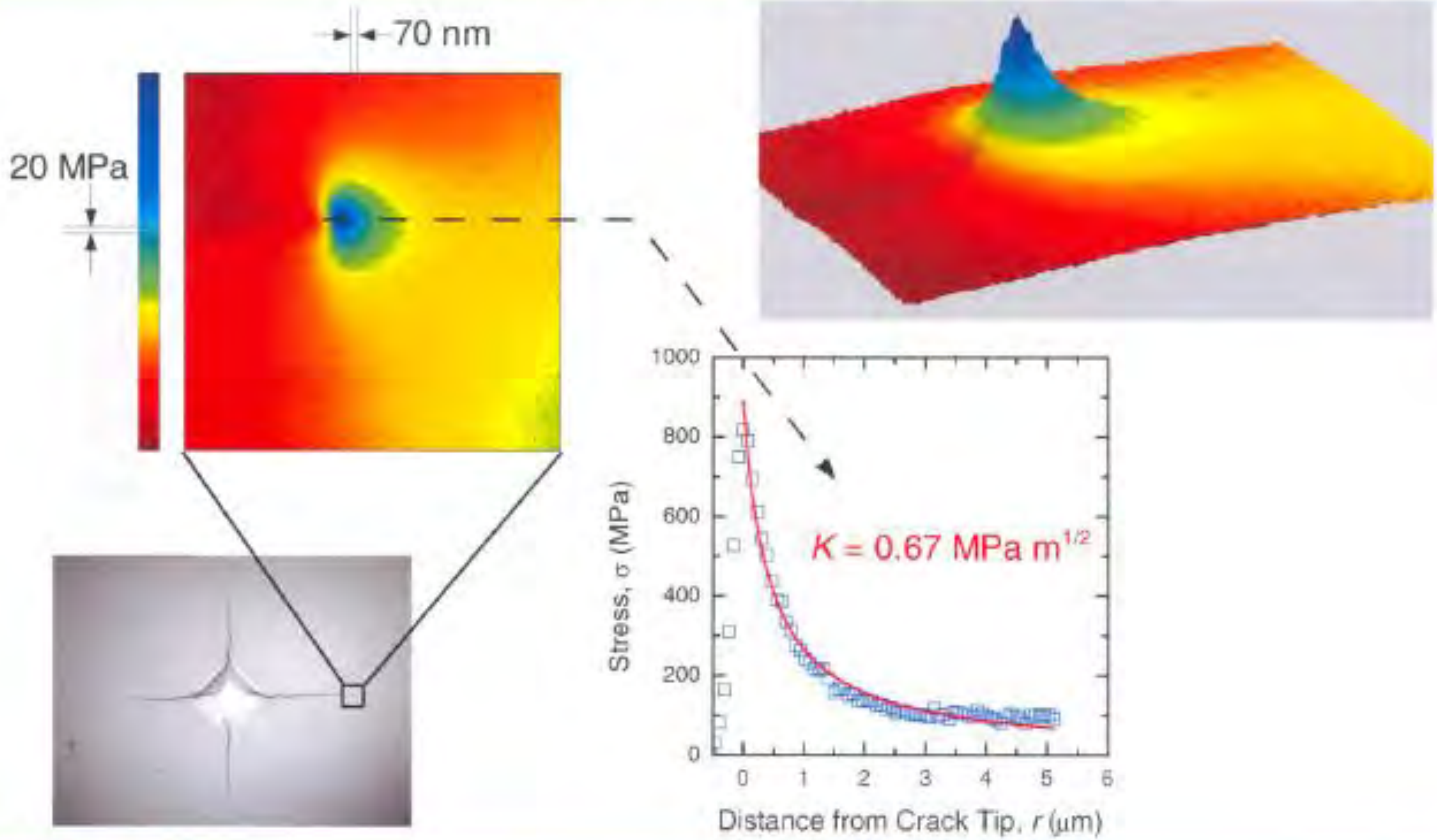
elastic energy density

Energy flow – stress singularity

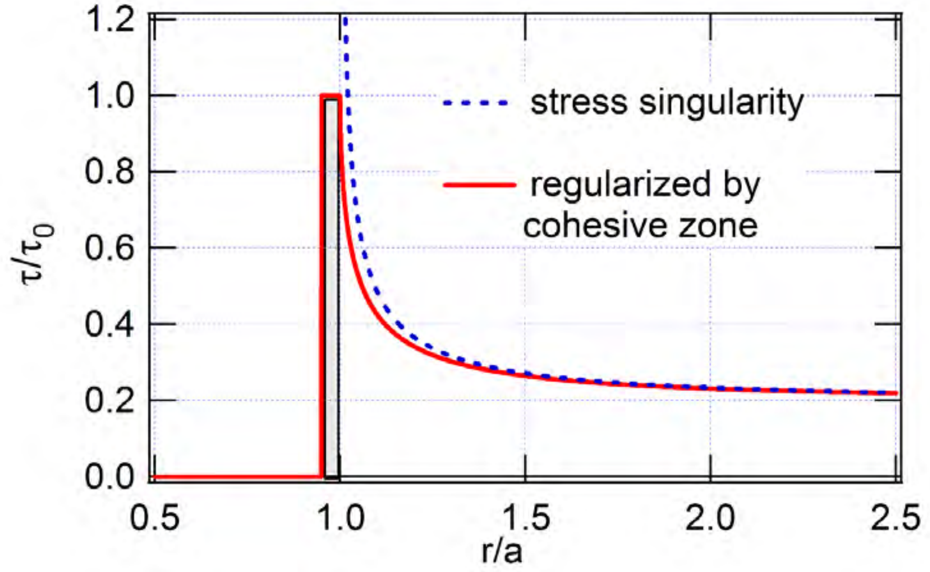


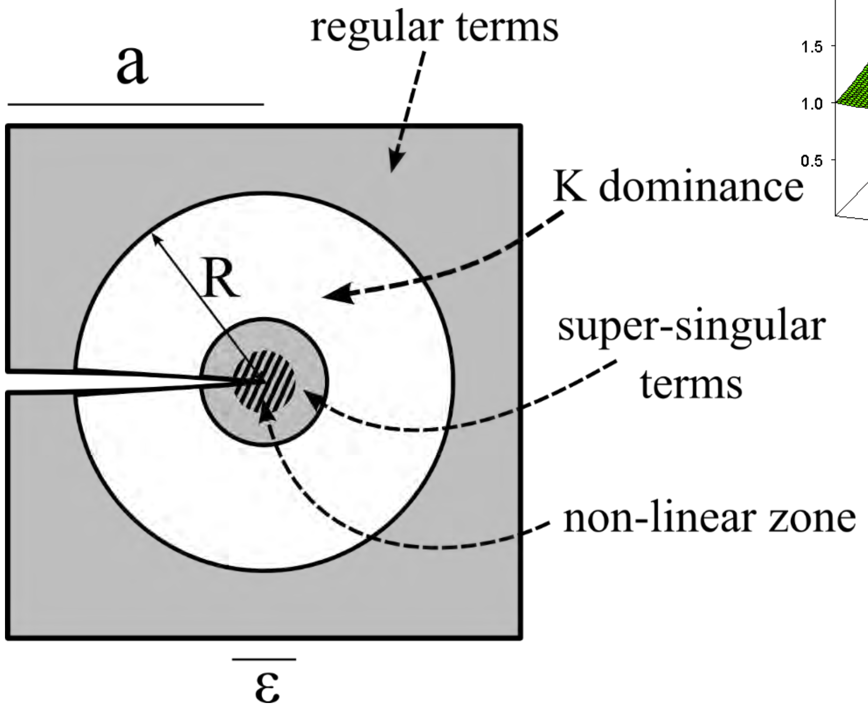


Direct Measurement of Stress-Intensity Factor

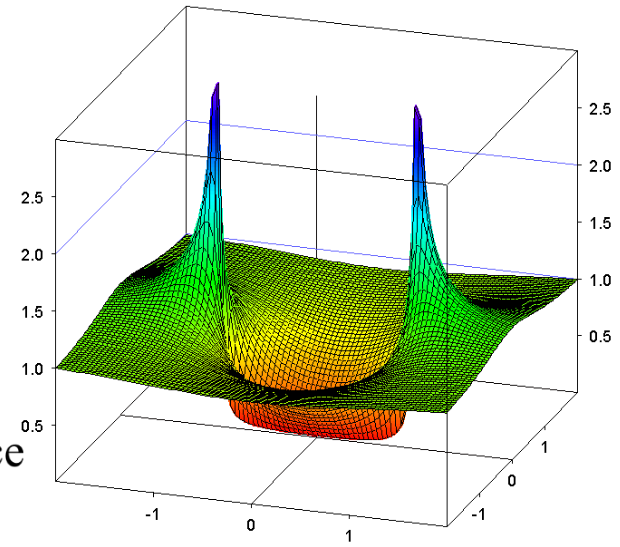


Different regions

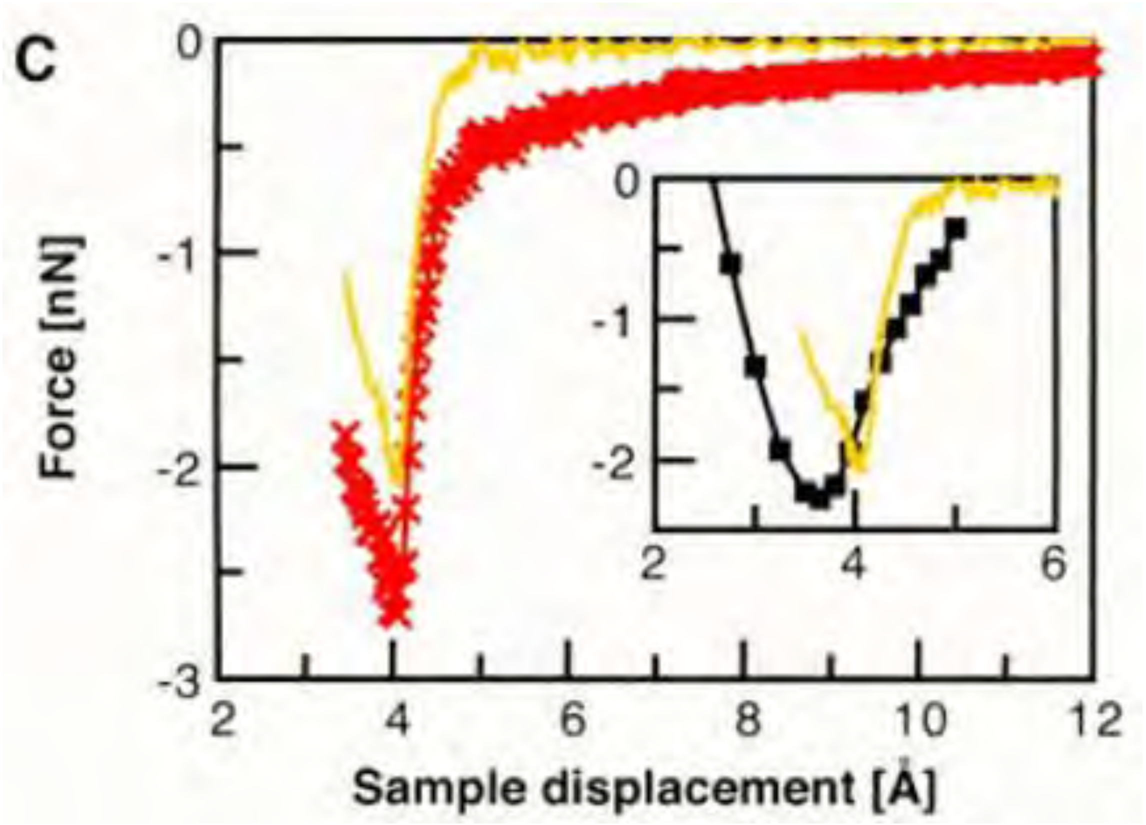




Hui & Ruina « Why K ? » 1993



Demonstration of some standard interactions

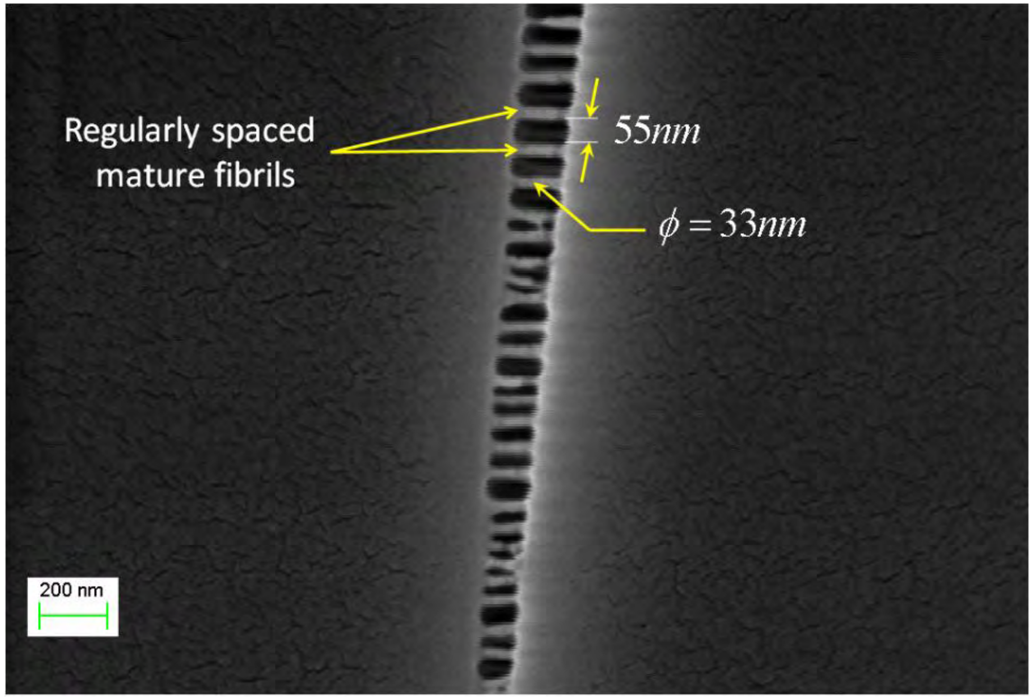


Si – Si

Lantz 2001

Damage - crazing

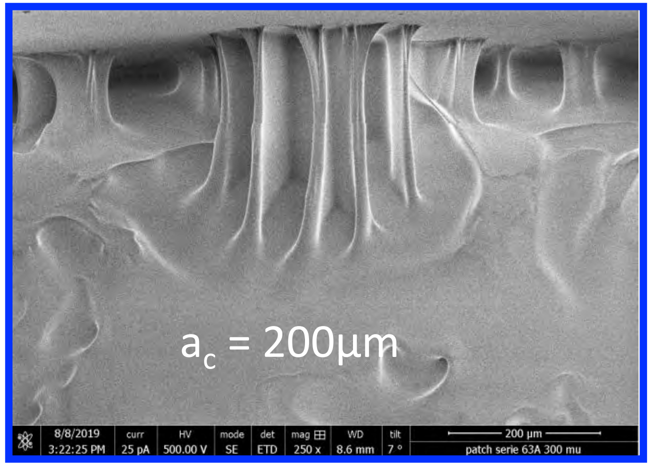
http://www.campoly.com/blog/antisocial-polymers/

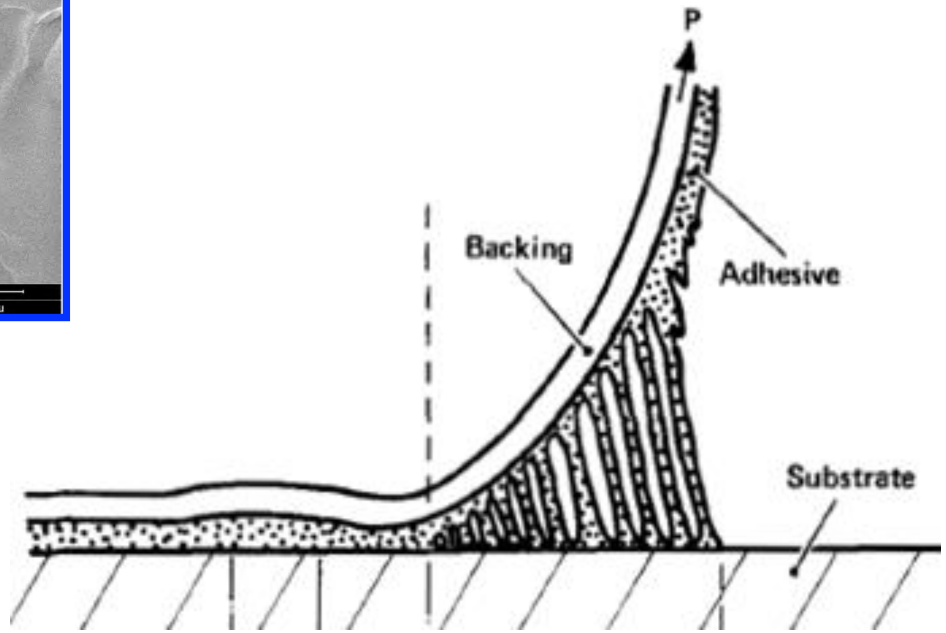


SEM image of a craze in Polystyrene

Image created by Y Arunkumar

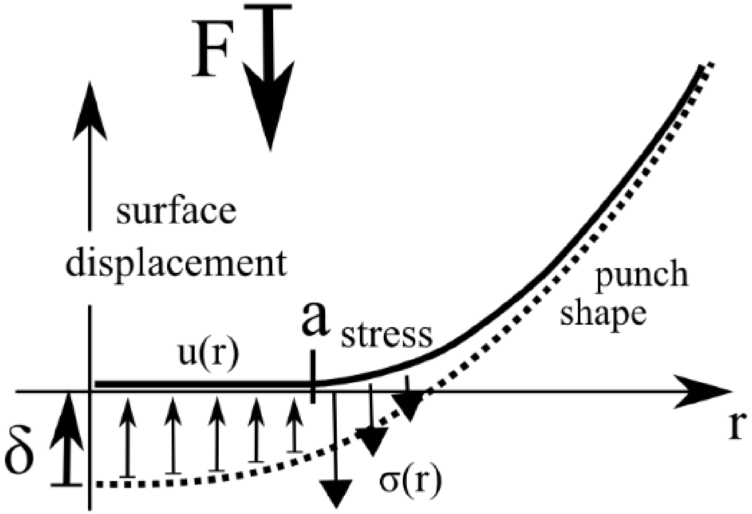
Pressure Sensitive Adhesives

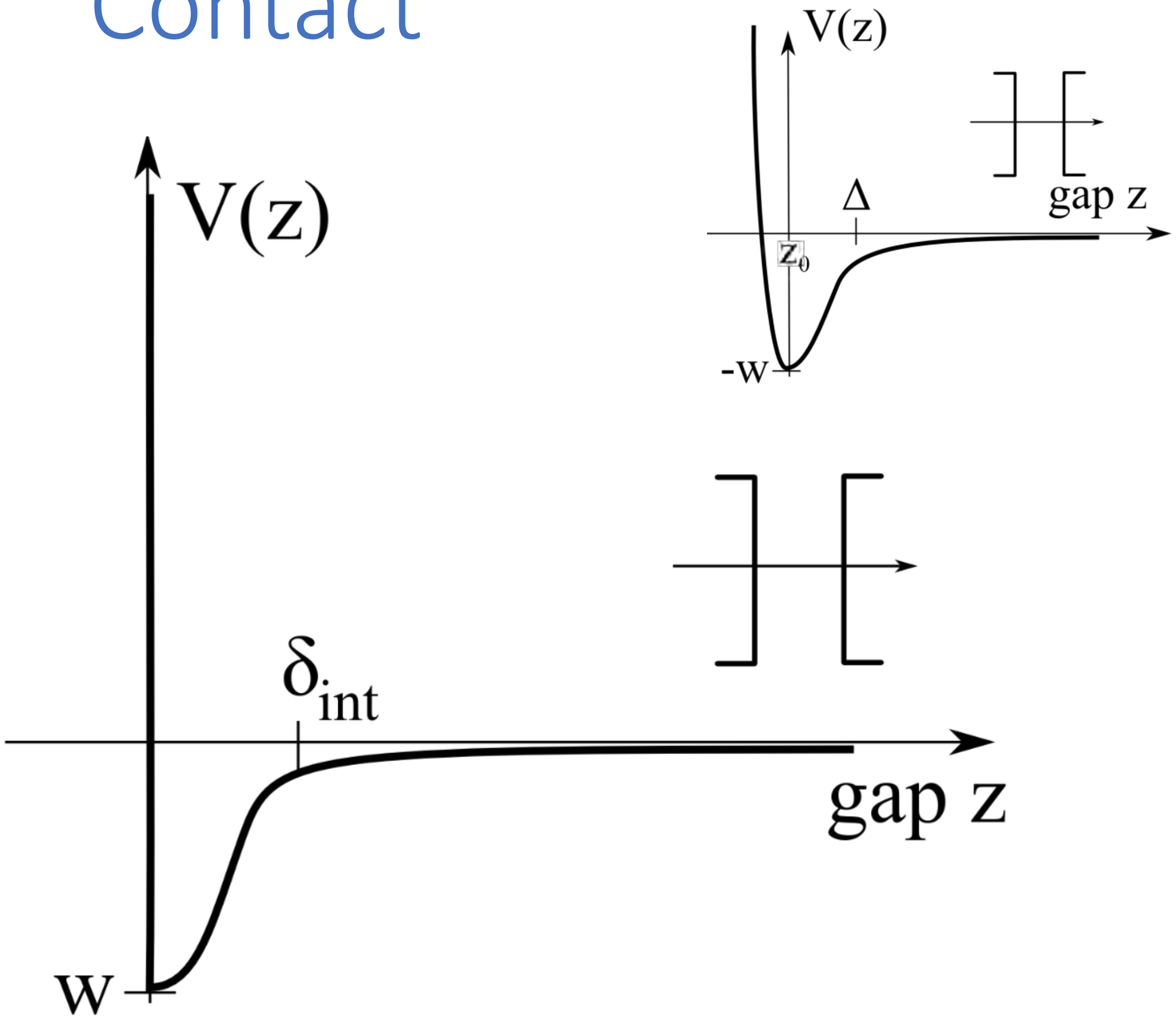




Kaelble

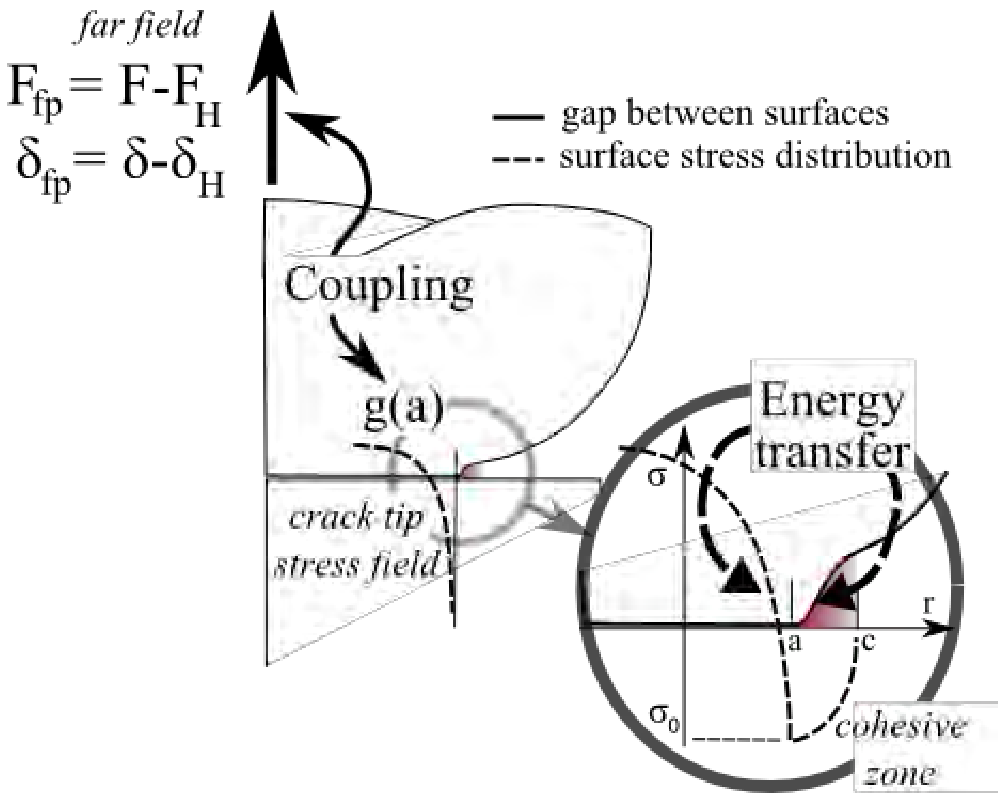
Contact



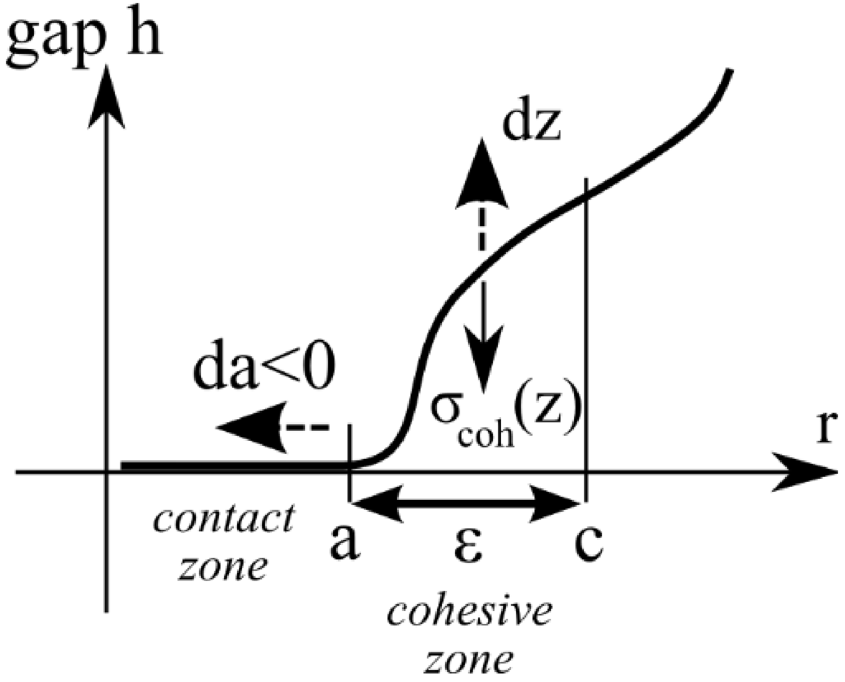


Barthel JCIS 1998

Energy flux

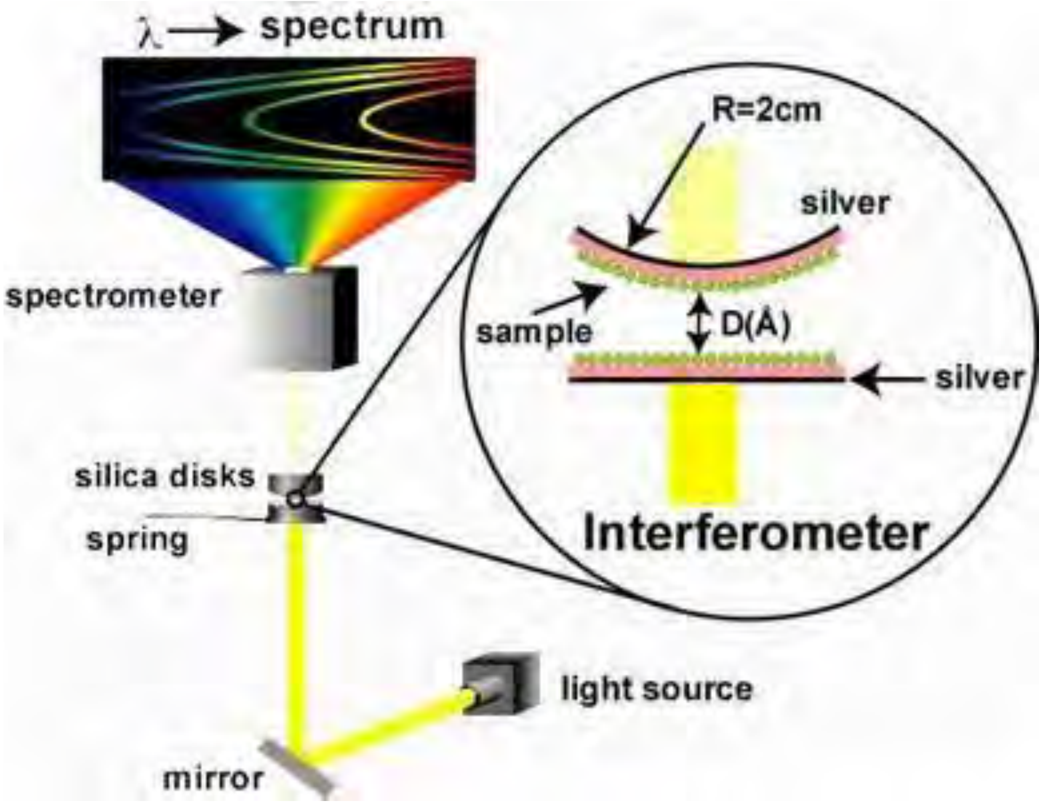


far field
$F_{fp} = F - F_H$
$\delta_{fp} = \delta - \delta_H$
gap between surfaces
surface stress distribution
Coupling
g(a)
crack tip
stress field
Energy
transfer
σ
r
a
c
σ_0
cohesive
zone



gap h
dz
da<0
$\sigma_{coh}(z)$
r
contact
zone
a
ε
c
cohesive
zone

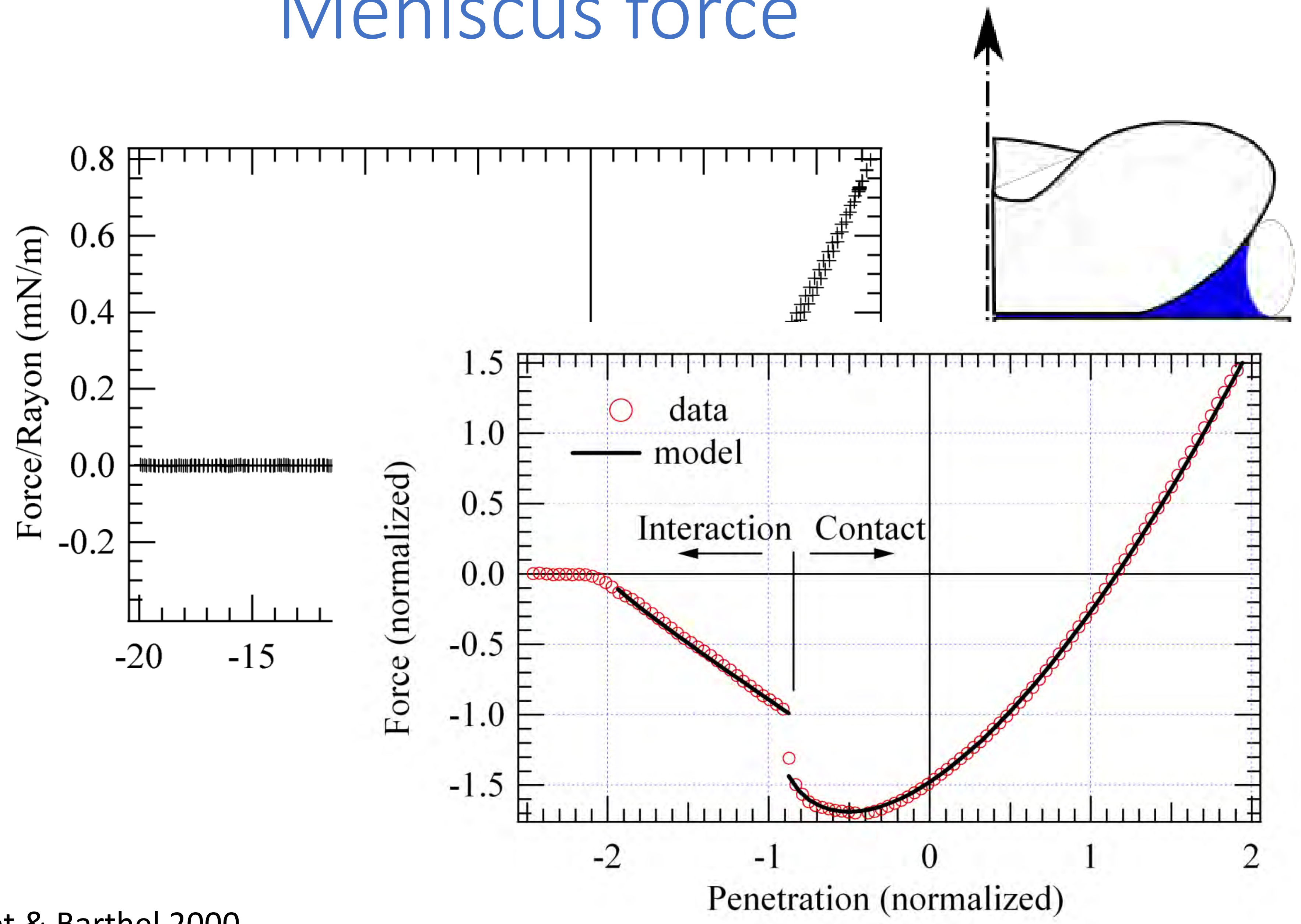
Mesurement devices - SFAs



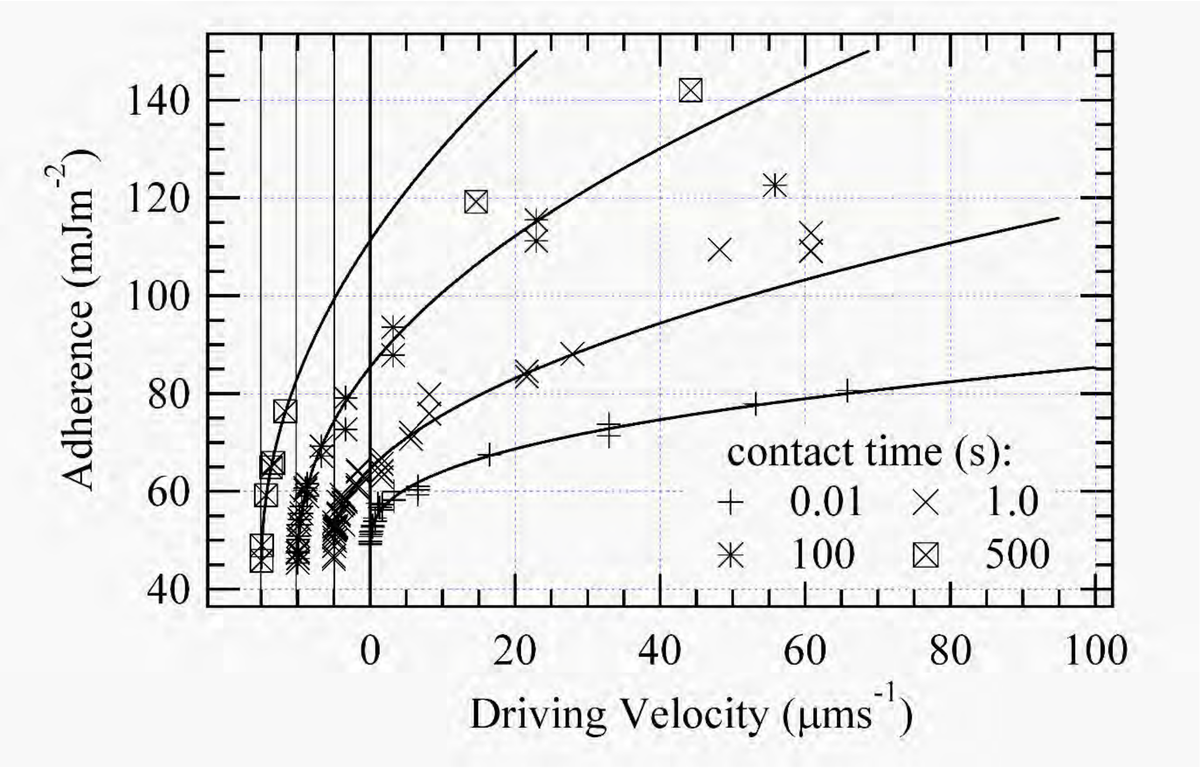
Tabor, Israelachvili

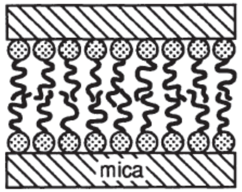
Tonk, Georges, Loubet

Meniscus force

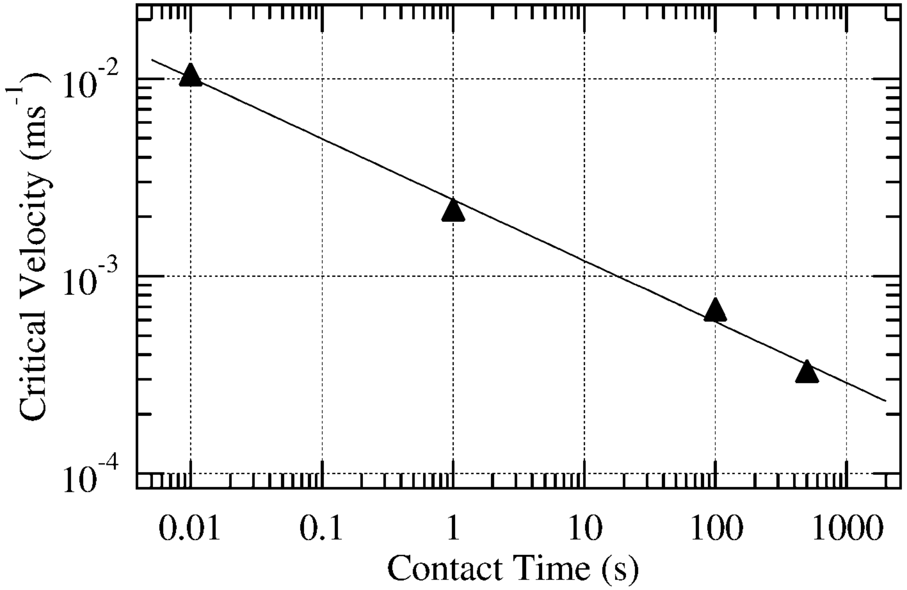


Barthel 1996, Huguet & Barthel 2000



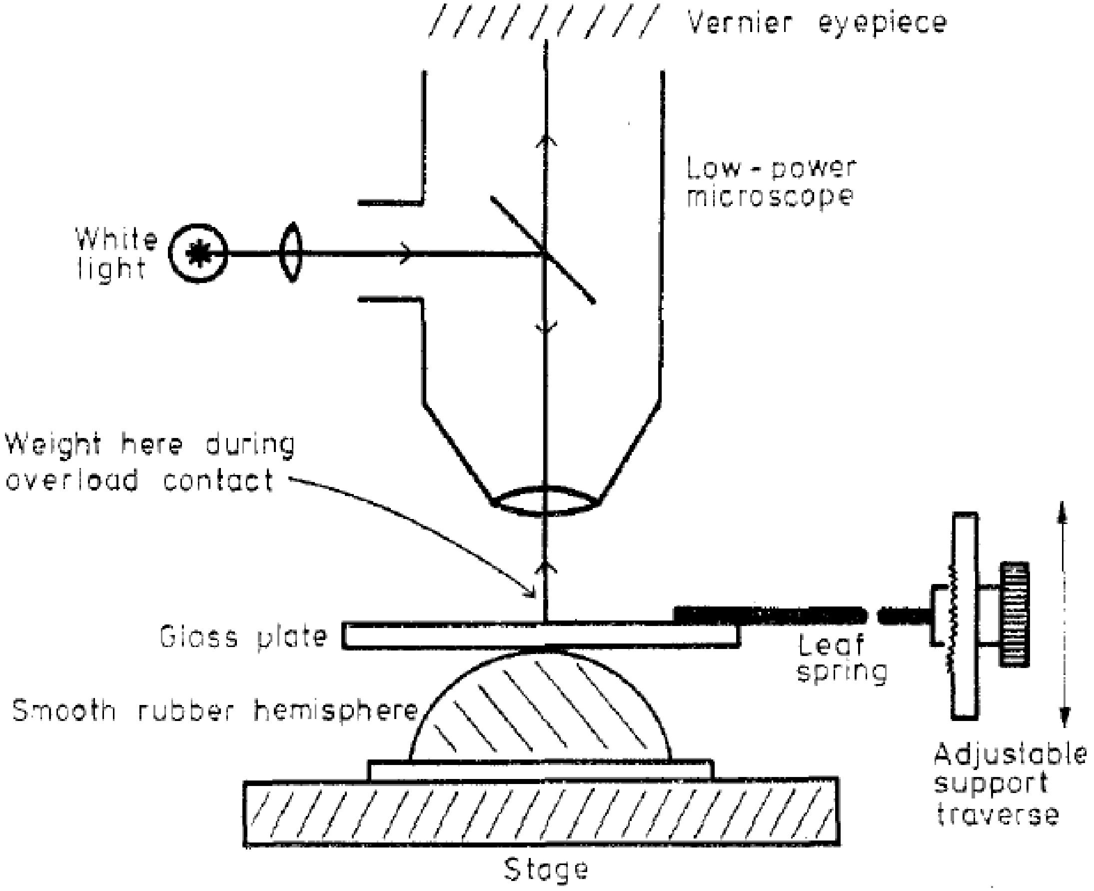


$$w = w_0 \left\{ 1 + \left(\frac{1}{v_0} \frac{da}{dt} \right)^{\beta} \right\}$$



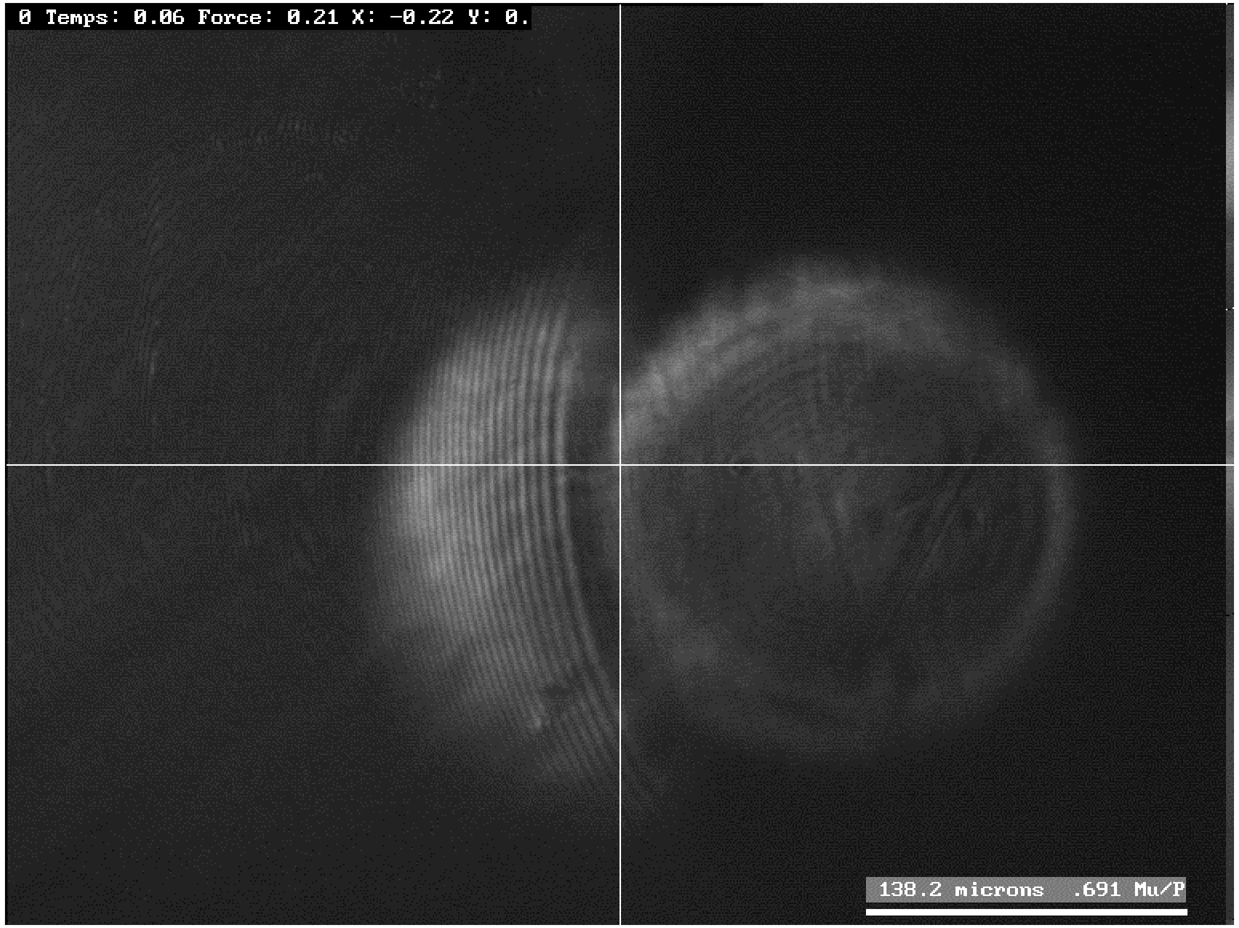
Ruths & Granick 1998, Barthel & Roux 2001

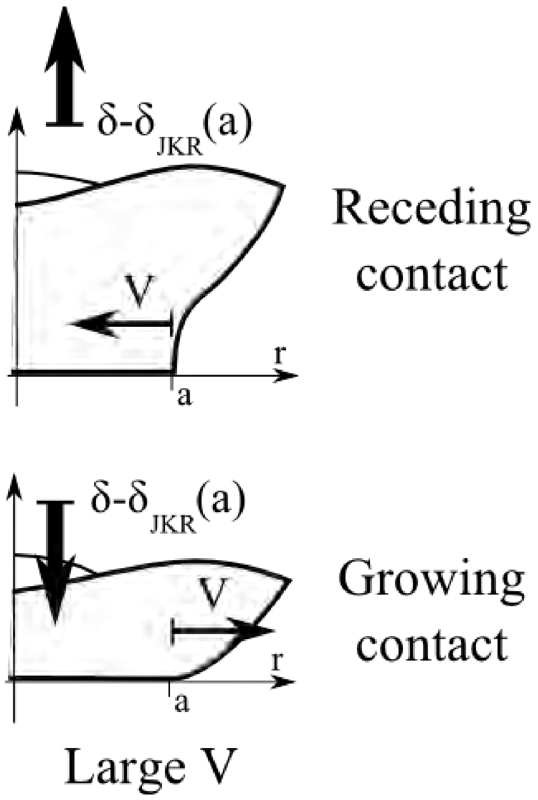
Another device



Surface charge contribution in rubber adhesion and friction, A. Roberts Journal of Physics D: Applied Physics 10, 1977, 1801

Non linear elastic coupling

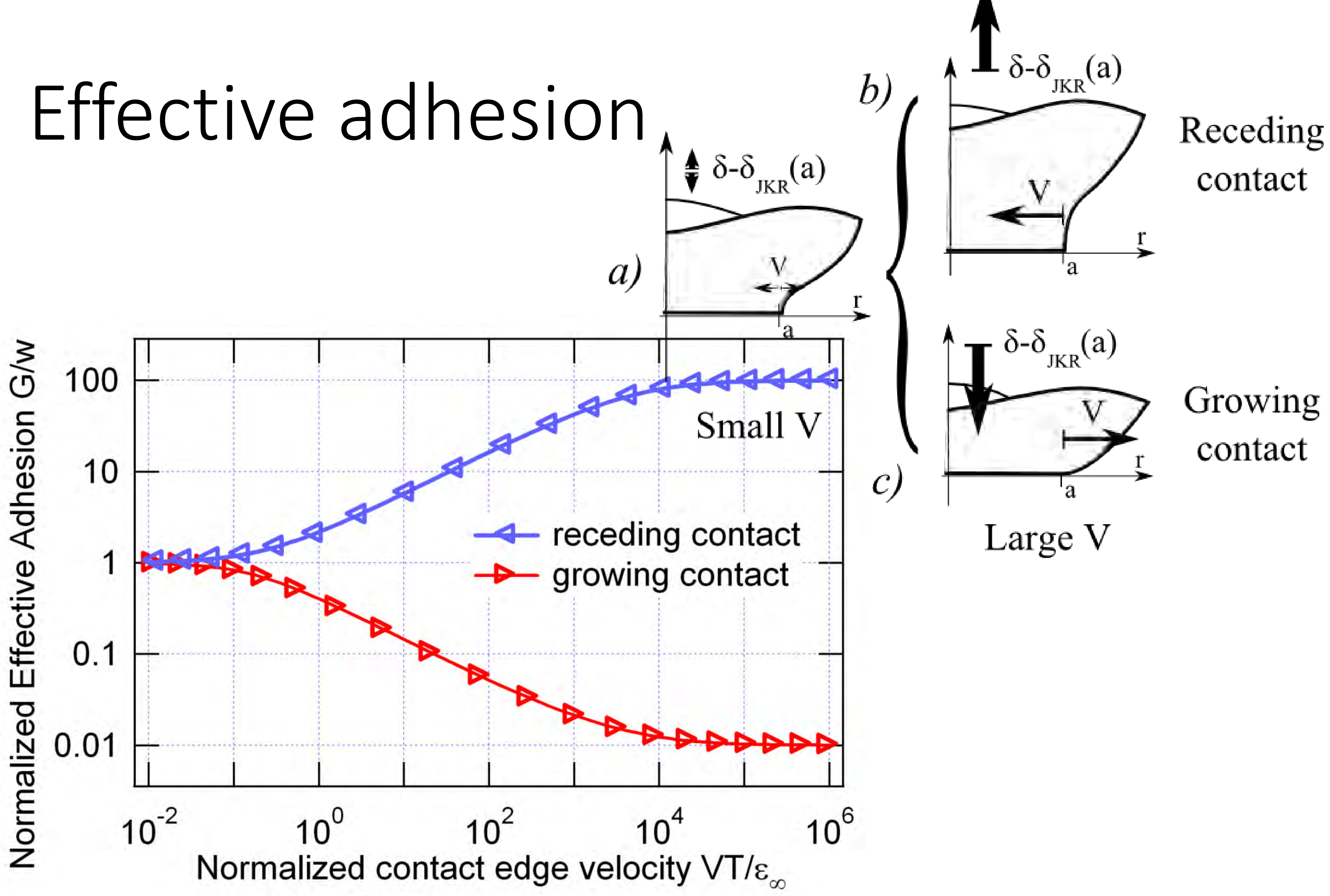




T above Tg

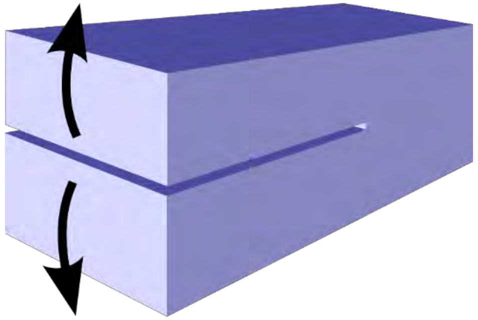
C. Gauthier, ICS, Strasbourg

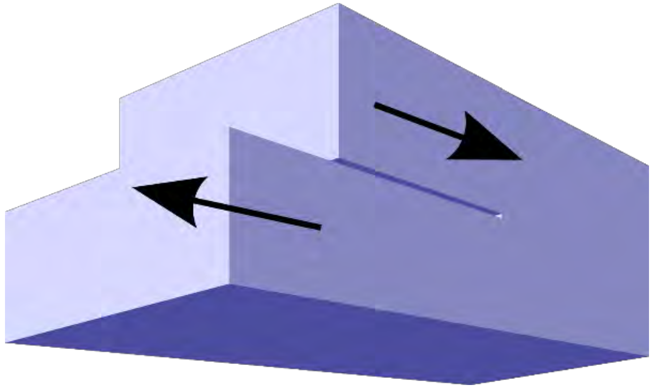
Effective adhesion

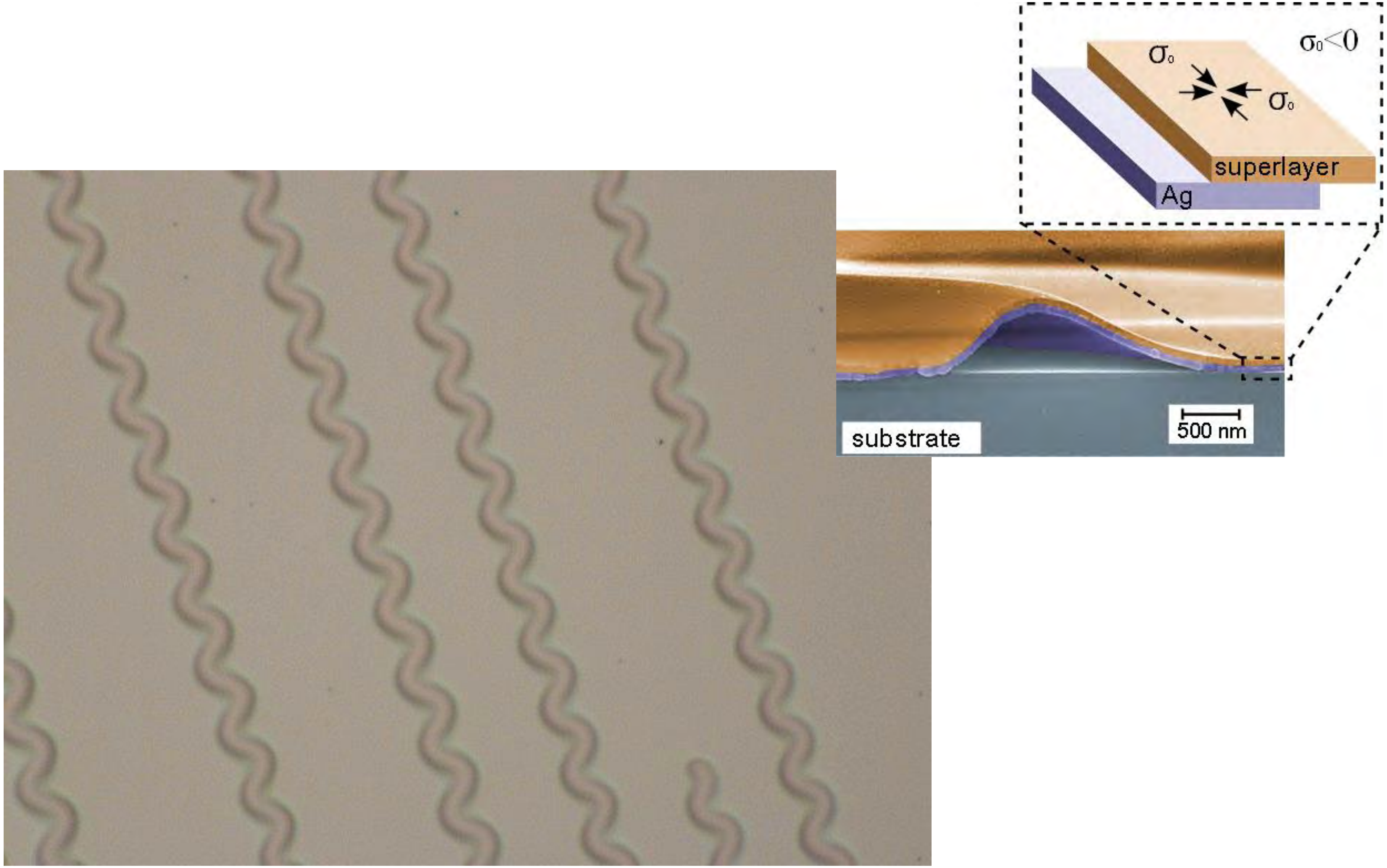


Barthel J. Phys. D 2009

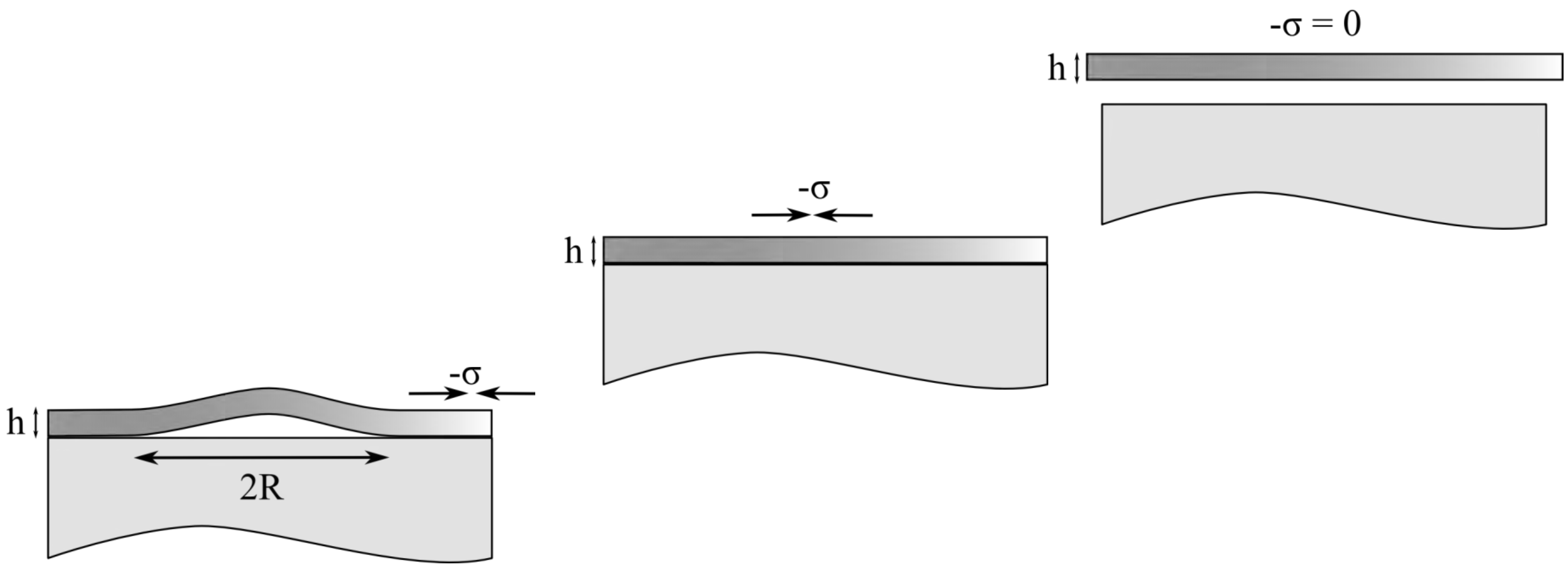
With shear



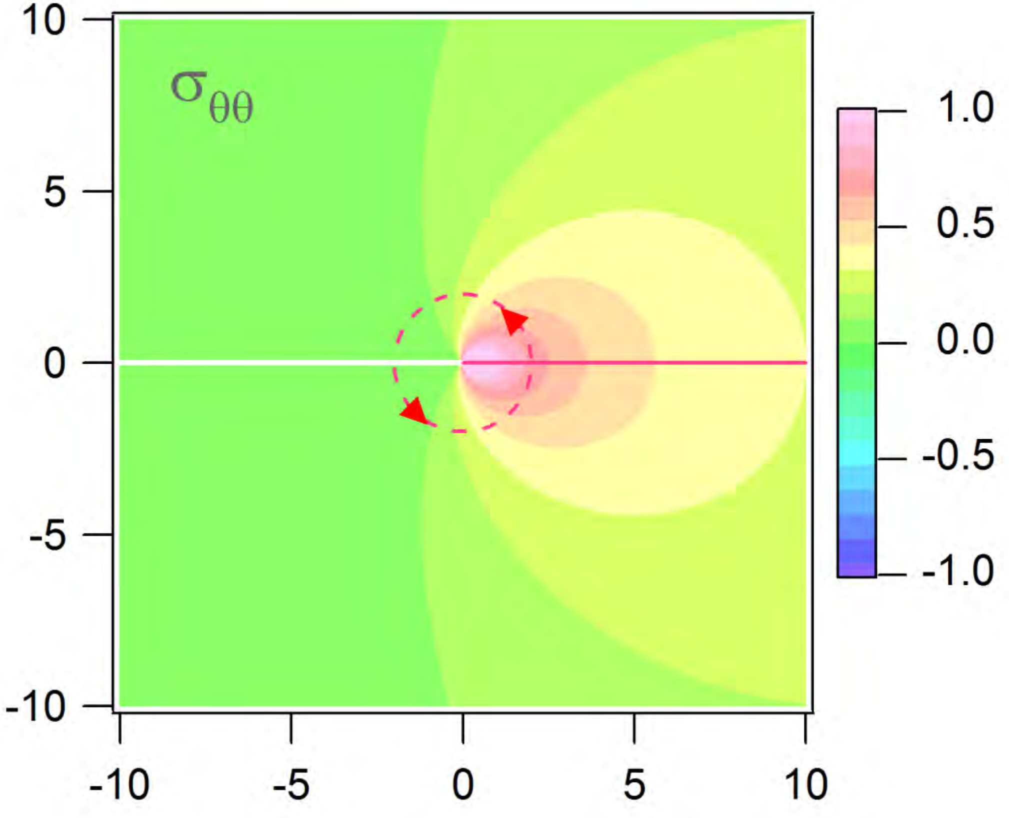


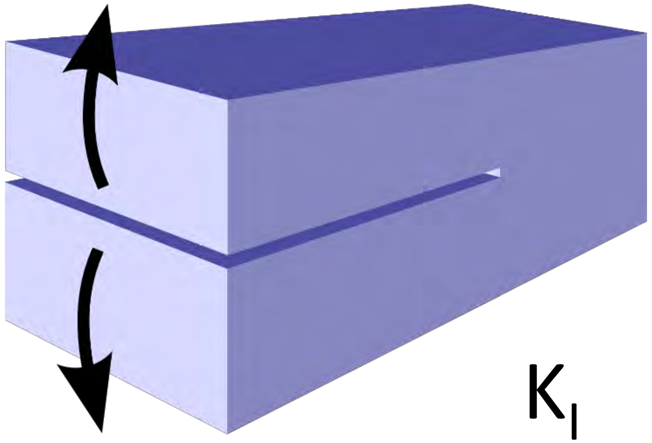


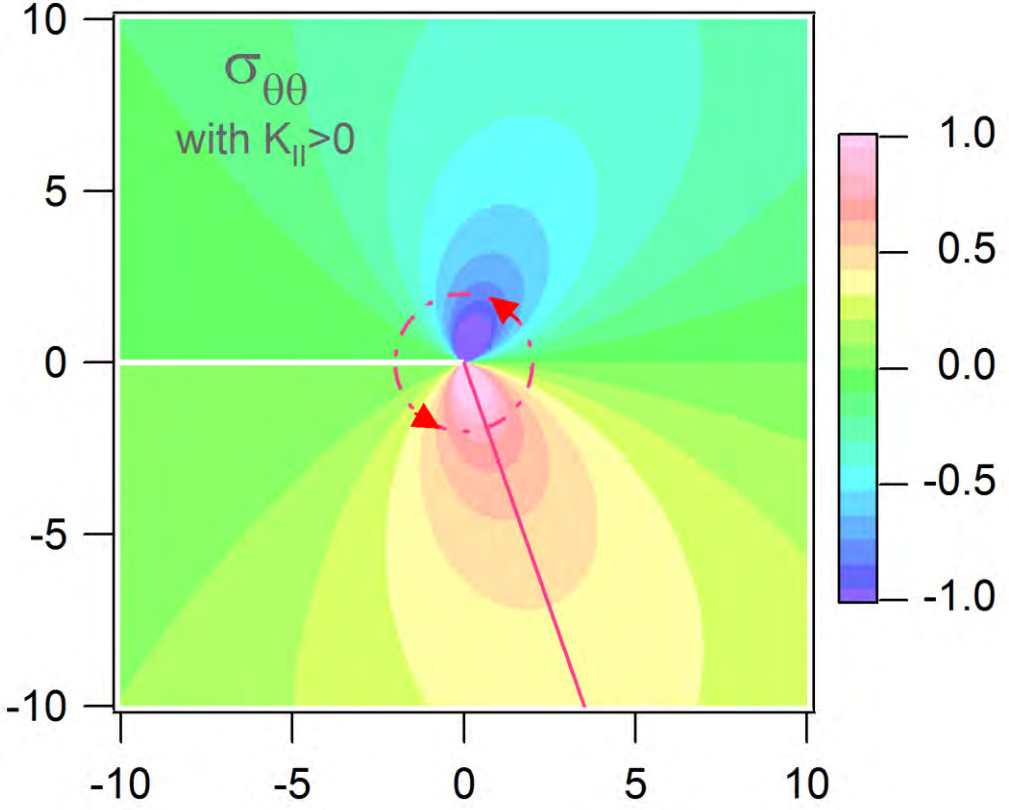
Faou 2012

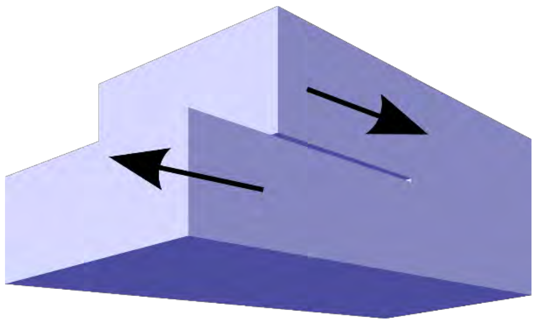


$$\sigma_c = \frac{\pi^2 D}{b^2 h}$$

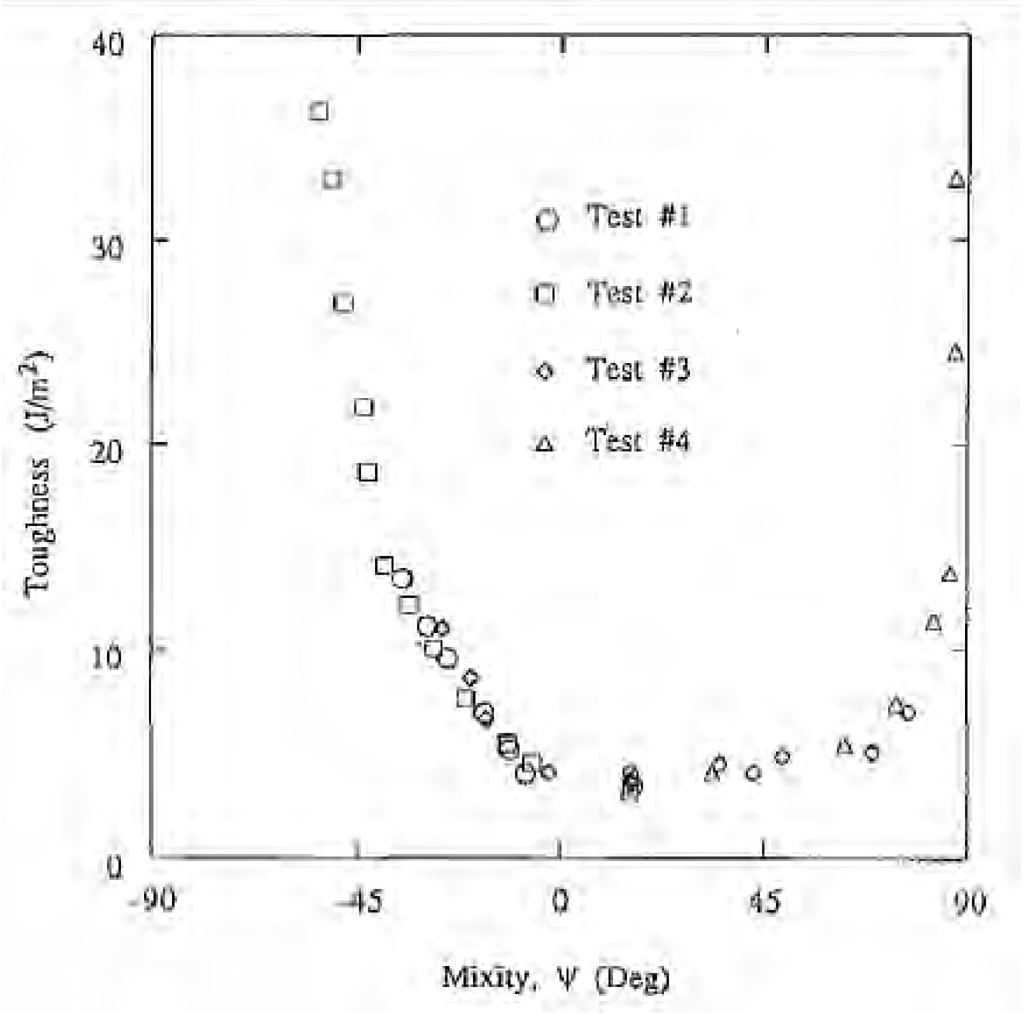

σθθ
10
5
0
-5
-10
-10
-5
0
5
10
1.0
0.5
0.0
-0.5
-1.0

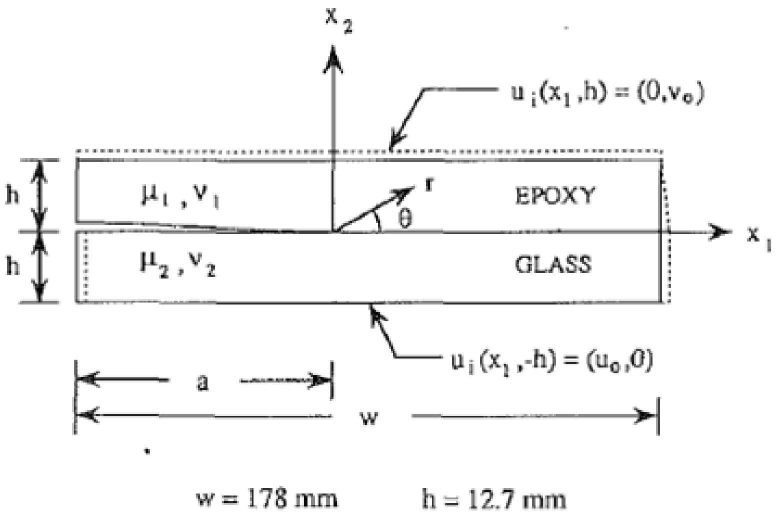

K_I





K_{II}

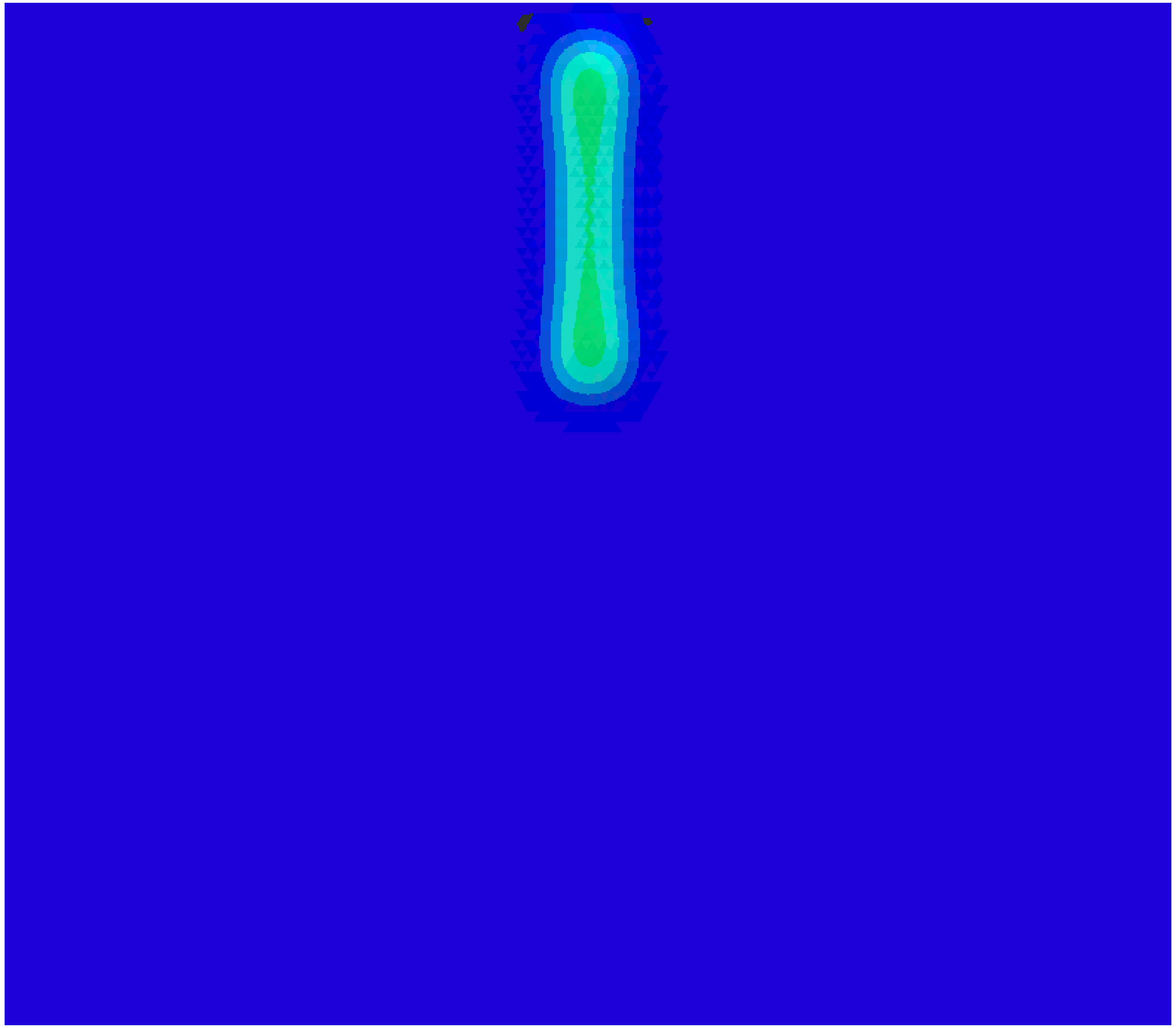




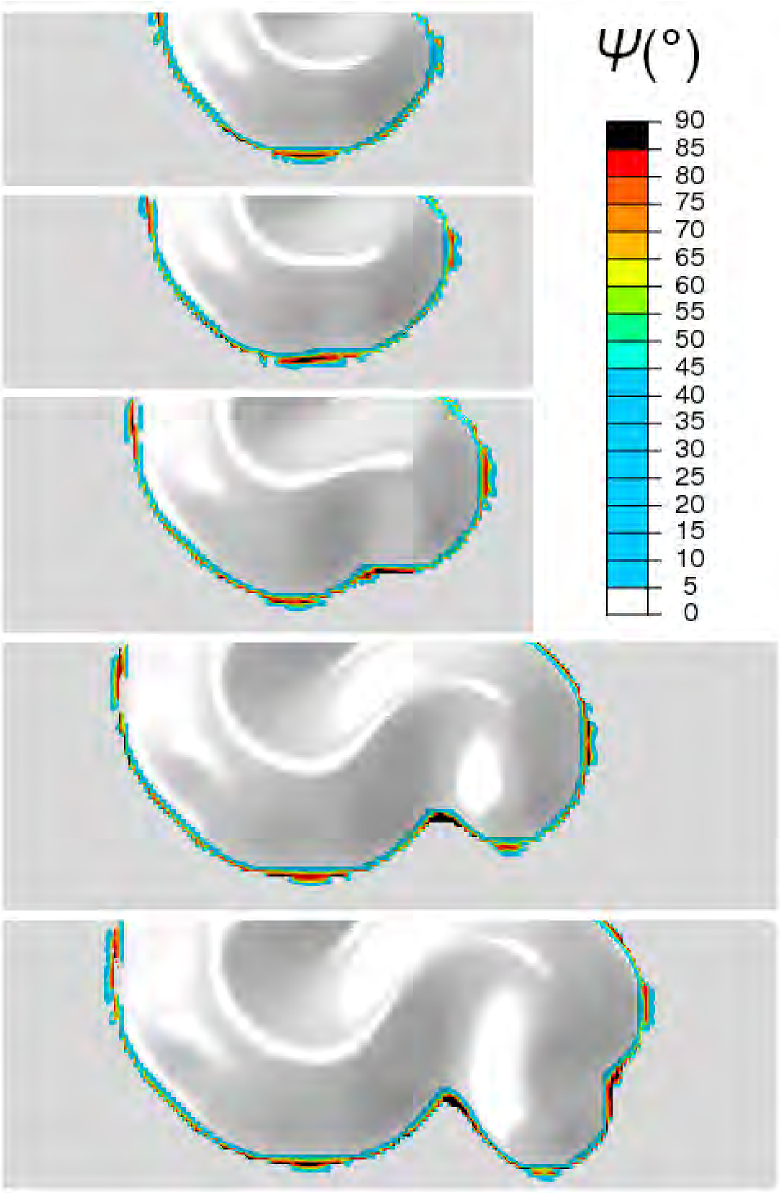
$$\psi = \tan^{-1}\left(\frac{K_{\mathrm{II}}}{K_{\mathrm{I}}}\right)$$

$$G = \frac{1}{2E^*}\left[K_{\mathrm{I}}^2 + \frac{2-\nu}{2-2\nu}K_{\mathrm{II}}^2\right],$$

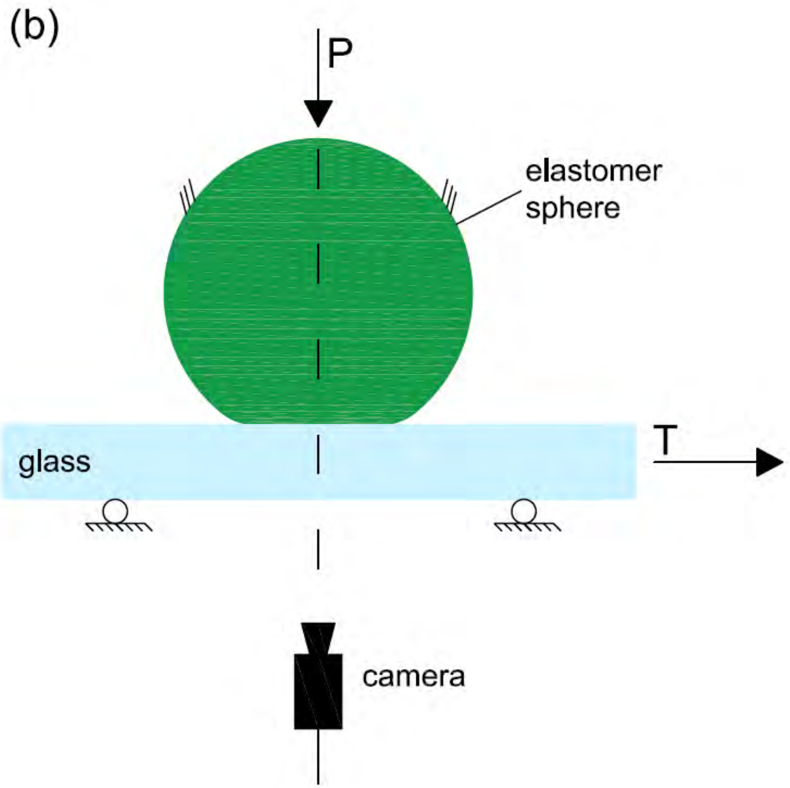
Liechti 92



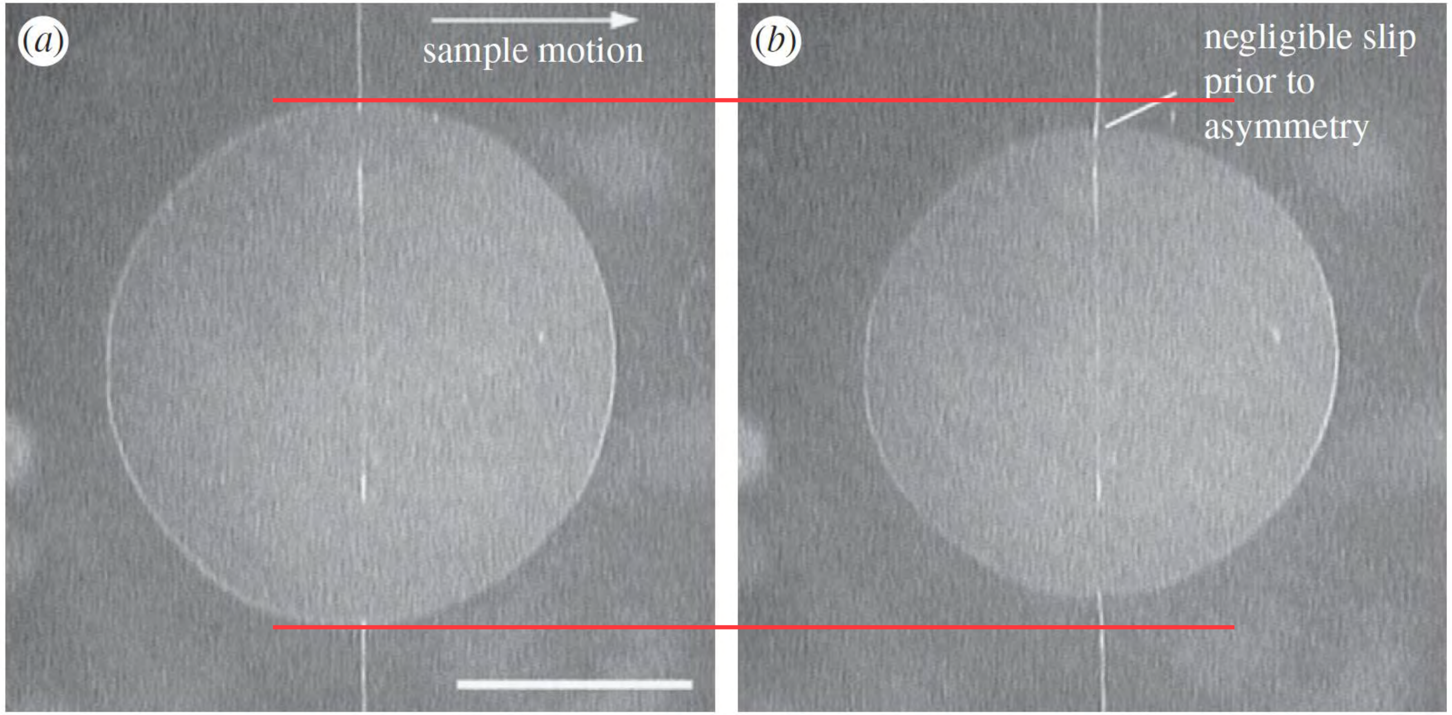
Faou 2012



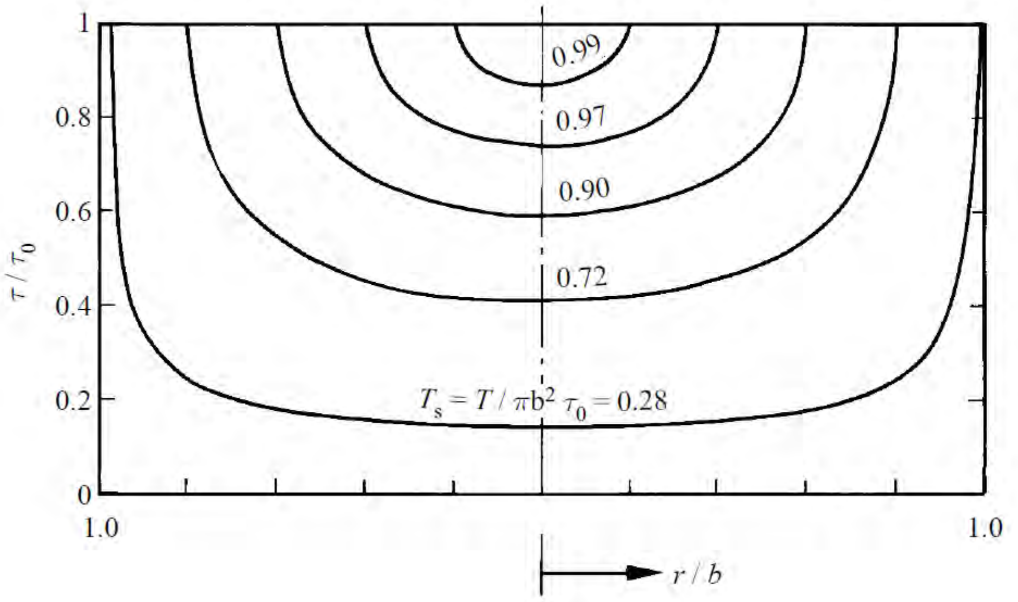
Coupling adhesion and friction



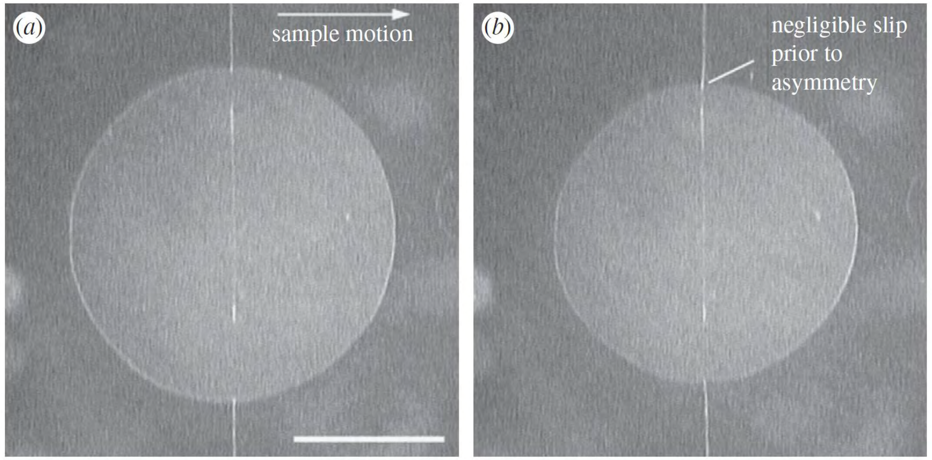
Papangelo 2019



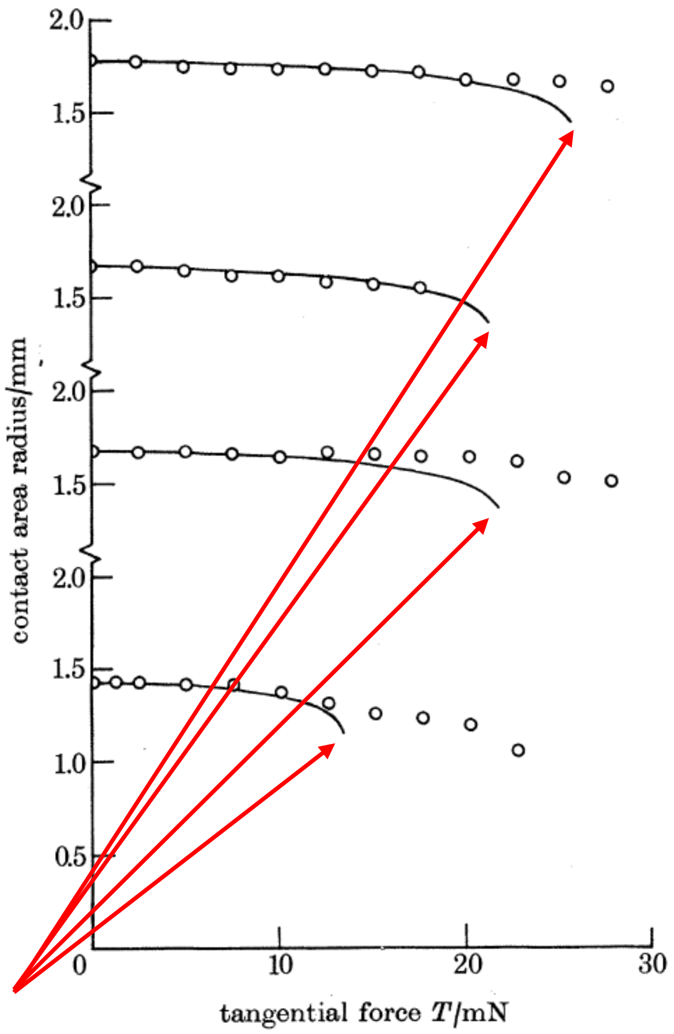
Waters 2010



Johnson 1997

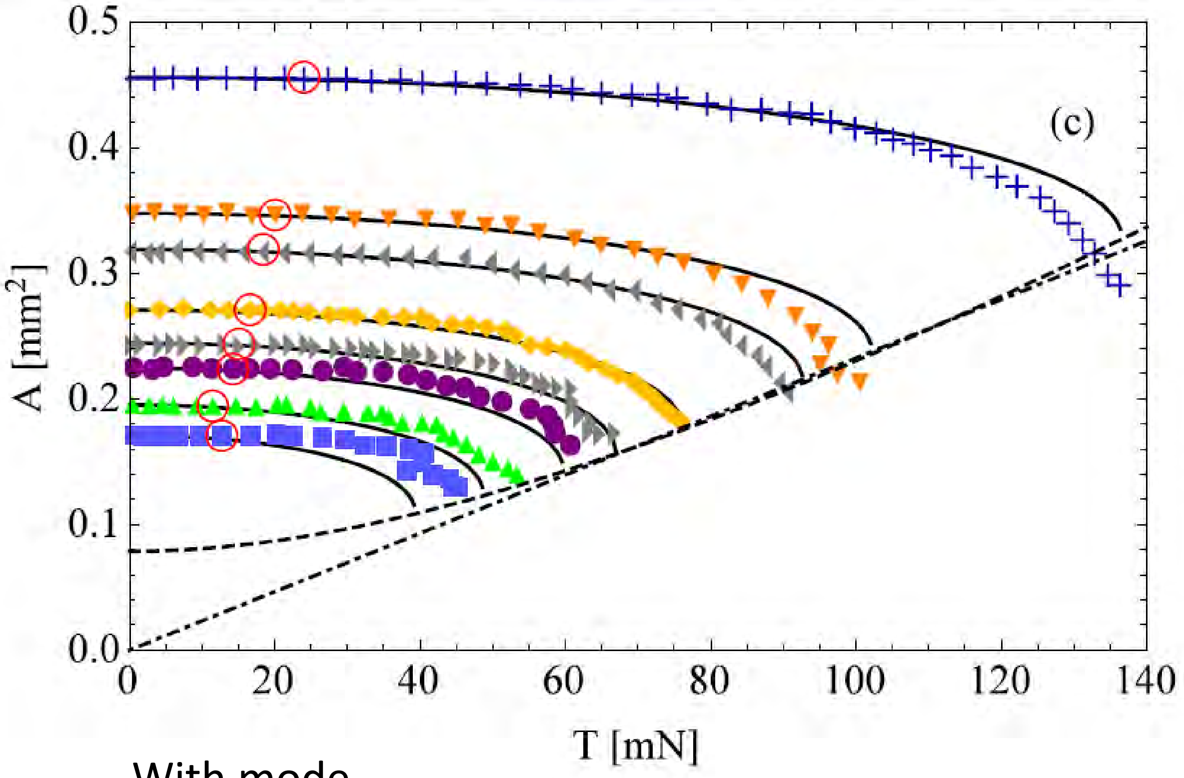


Waters 2010



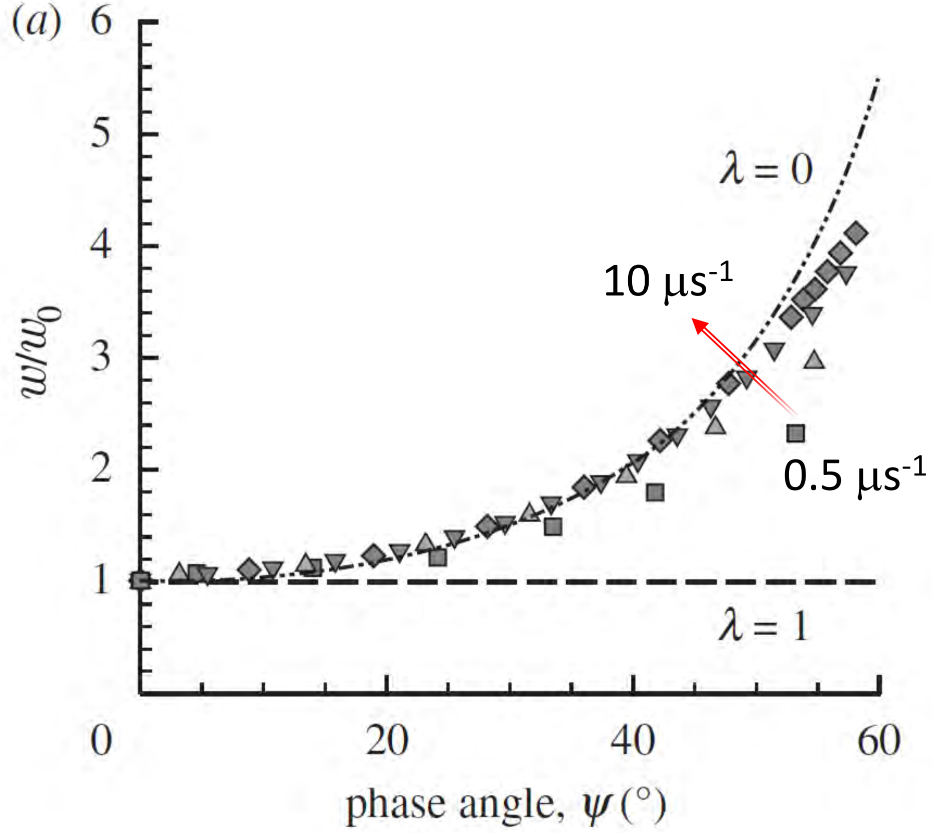
No mode
mixity dependance !

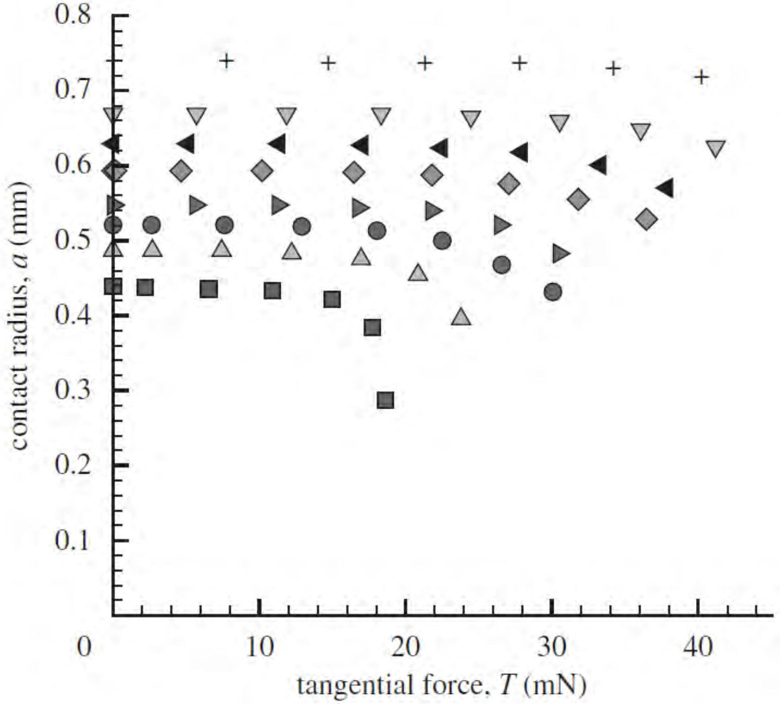
Savkoor & Briggs 1977



With mode
mixity dependance !

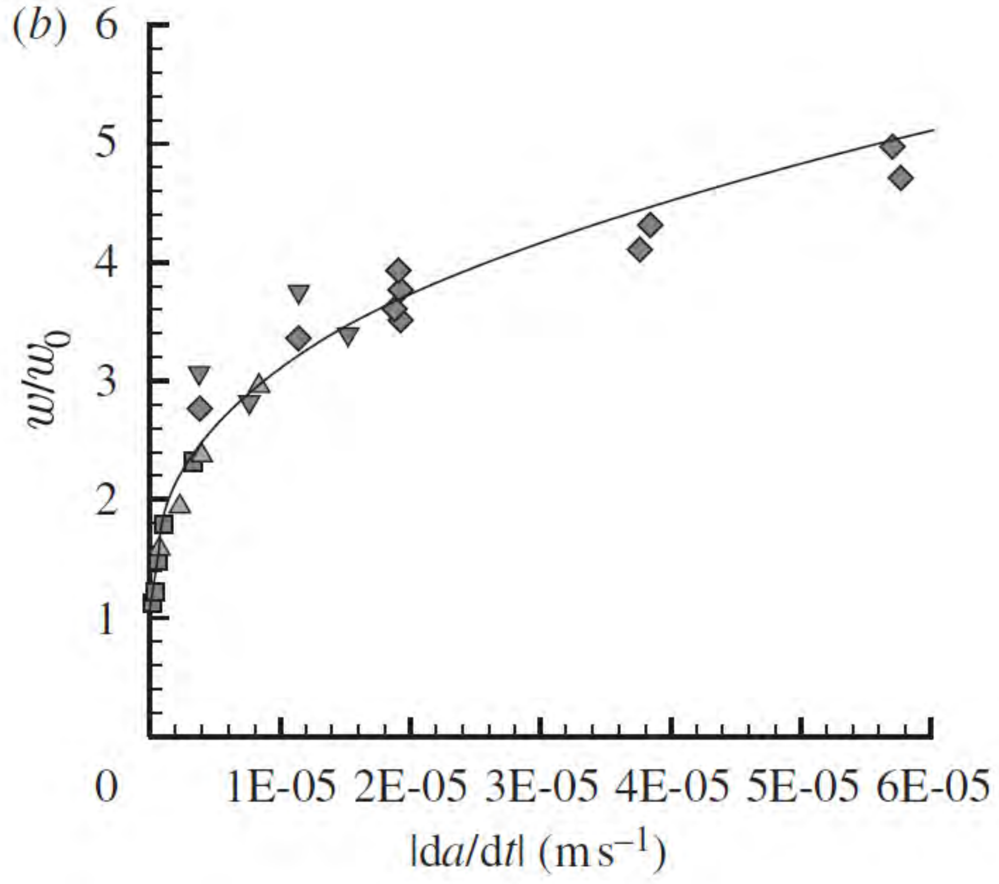
Papangelo 2019





$$w(\psi) = w_0\xi(\psi) = w_0\left(1 + \frac{2-\nu}{2-2\nu}\tan^2[(1-\lambda)\psi]\right),$$

Waters 2010



$$w = w_0 \left[1 + \left(\frac{1}{V_0} \frac{\mathrm{d}a}{\mathrm{d}t} \right)^{\beta} \right]$$

Waters 2010