Bo Persson

Research Center Juelich
Germany

Surface roughness

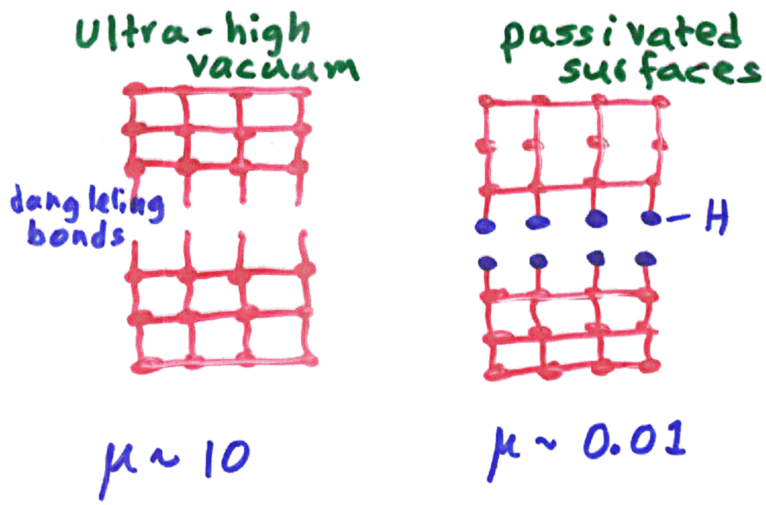
Contact mechanics

Adhesion

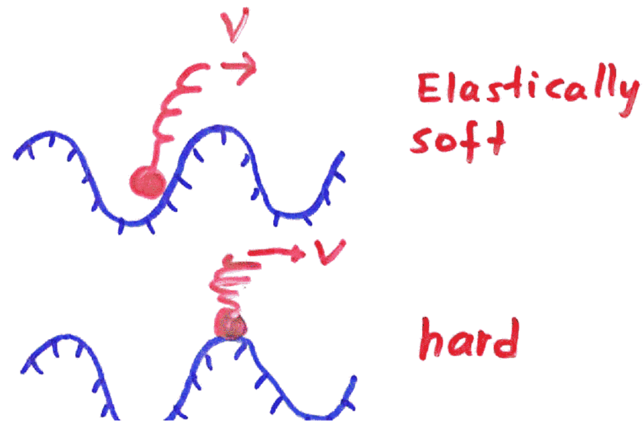
Crack propagation in rubber

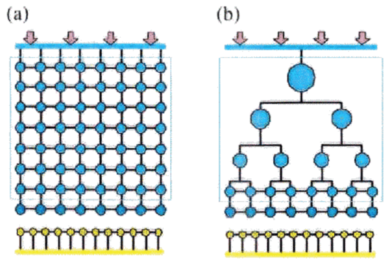
Rubber friction

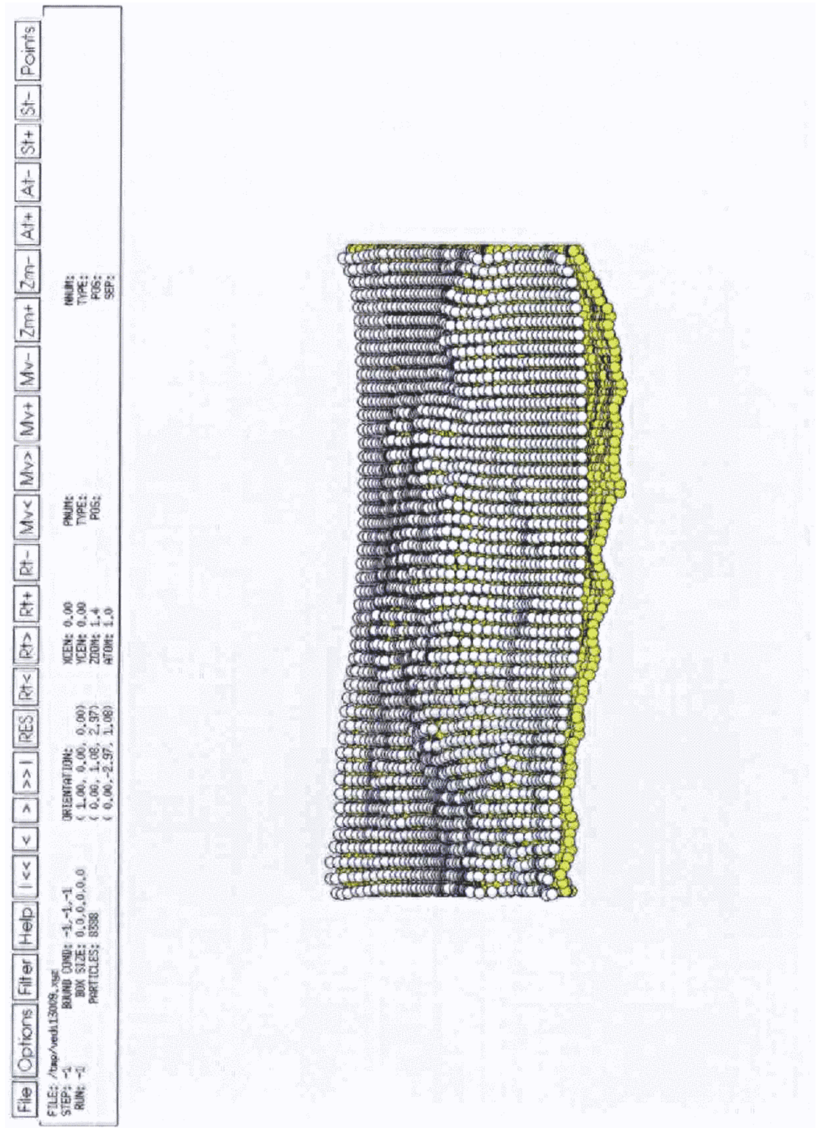
Diamond friction

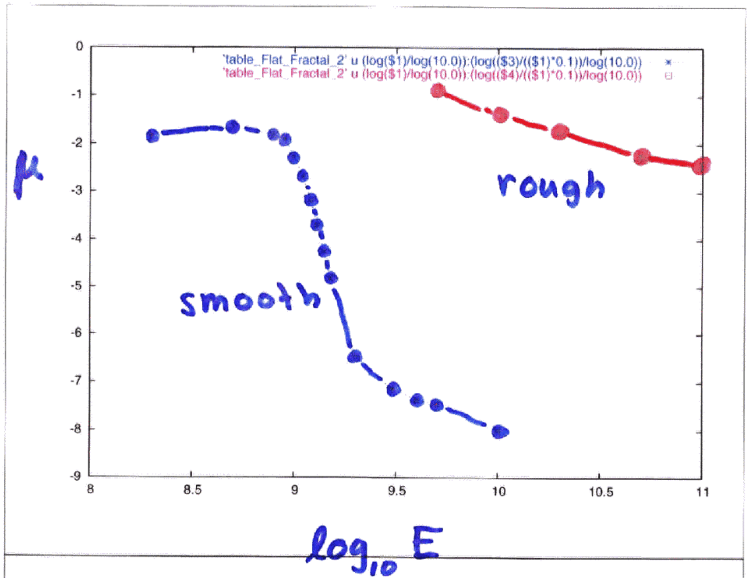


Elastic instability:

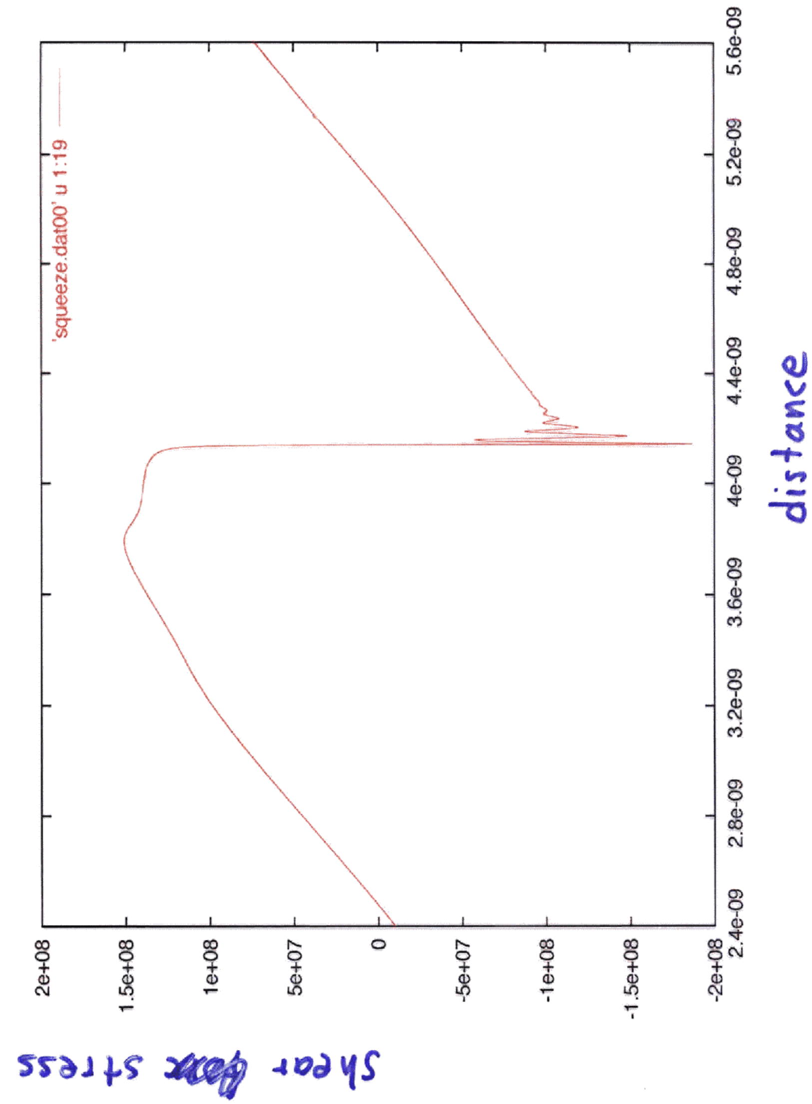



(a)
(b)


File
Options
Filter
Help
RES
Rt<
Rt>
Rt+
Rt-
Mv<
Mv>
Mv+
Mv-
Zm+
Zm-
At+
At-
St+
St-
Points

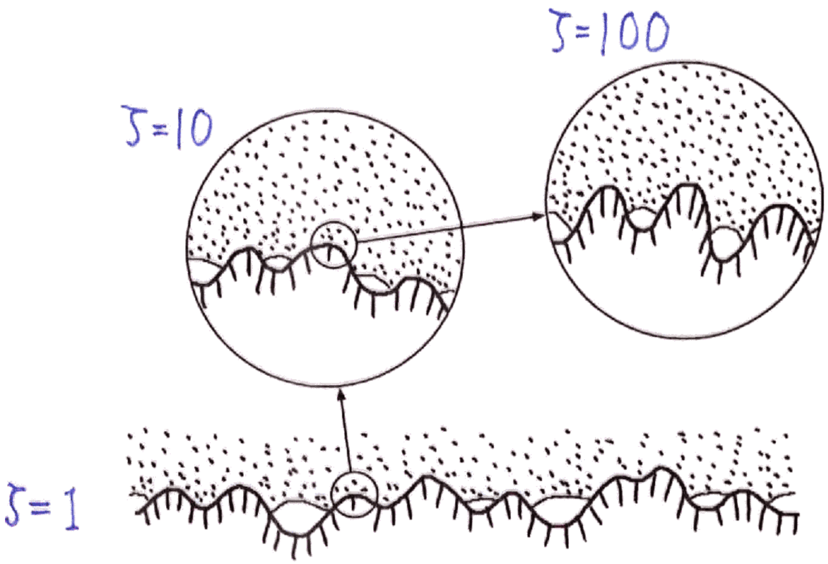


'table_Flat_Fractal_2' u (log($1)/log(10.0)):(log(($3)/(($1)*0.1))/log(10.0))
'table_Flat_Fractal_2' u (log($1)/log(10.0)):(log(($4)/(($1)*0.1))/log(10.0))
μ
rough
smooth
log10 E

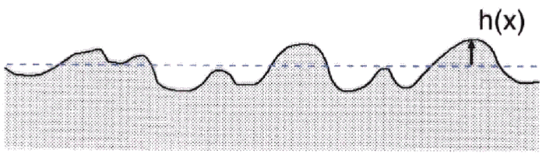


'squeeze.dat00' u 1:19
distance
shear stress

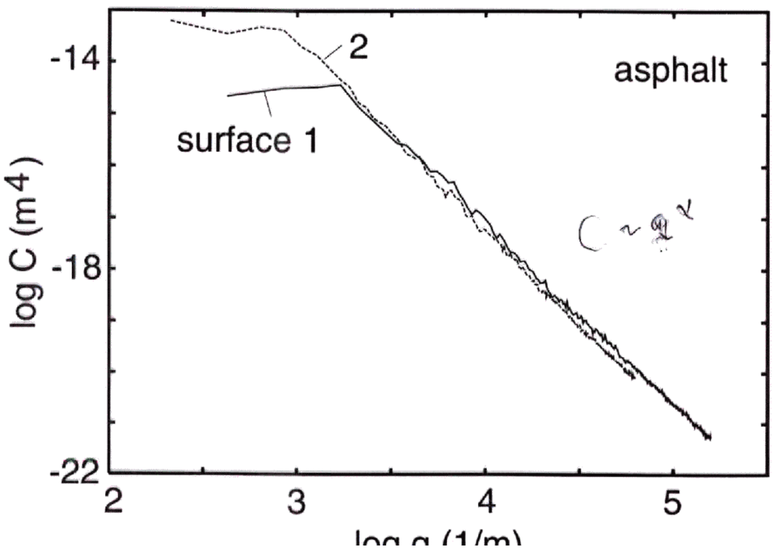
Many length scales:



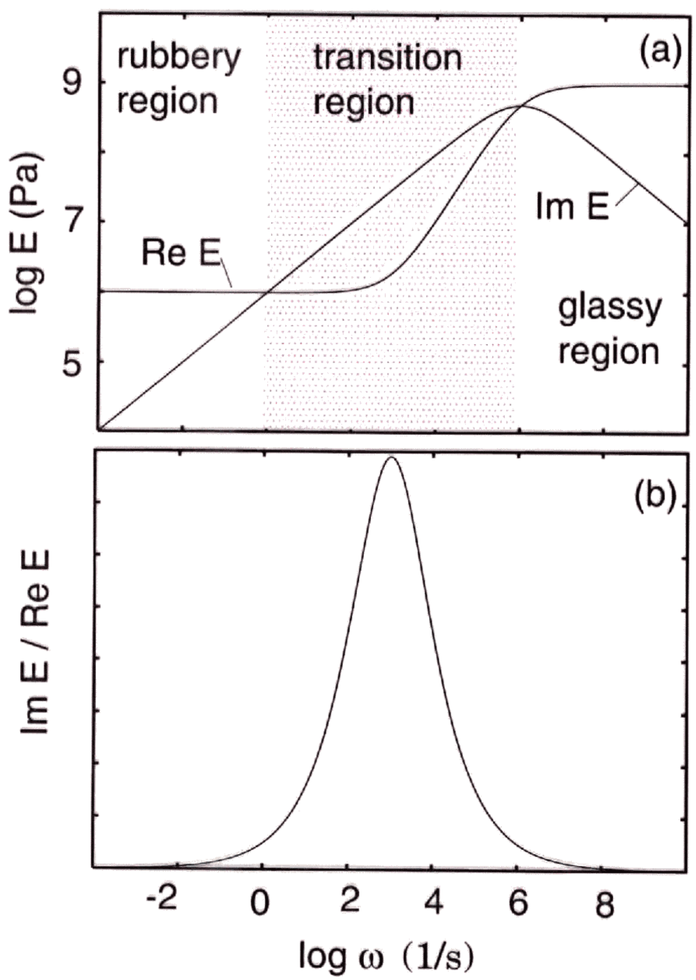
Surface roughness power spectra C(q)



$$C(q) = \int \langle h(x)h(0)\rangle e^{iqx}\, dA$$

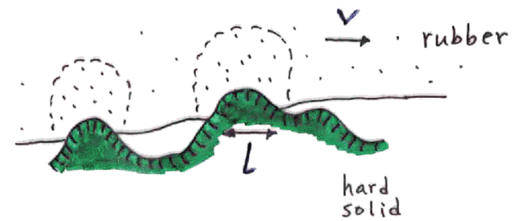


Viscoelastic Modulus E(ω)



Overview of Rubber friction processes

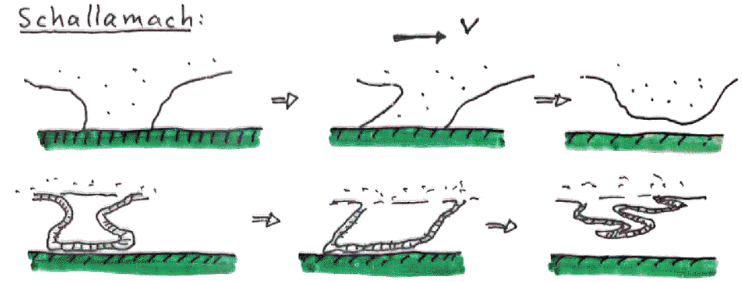
- Hysteric contribution:



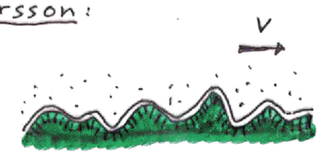
$$\omega \approx \frac{v}{L}$$

- Adhesion contribution:

Schallamach:



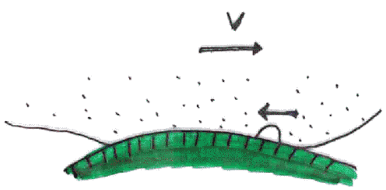
Persson:



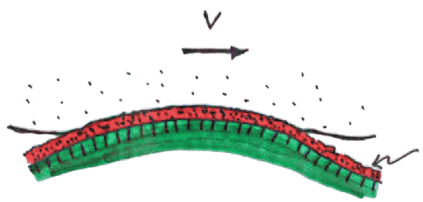
⇐ The same temperature dependence as that of the complex elastic

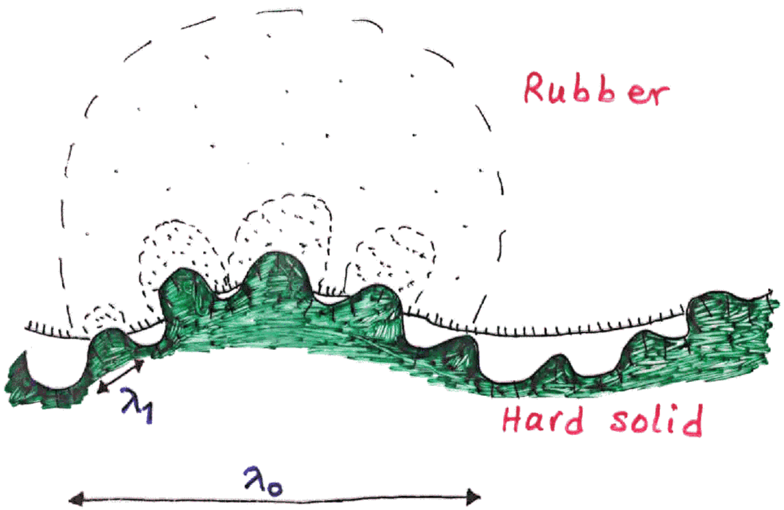
2

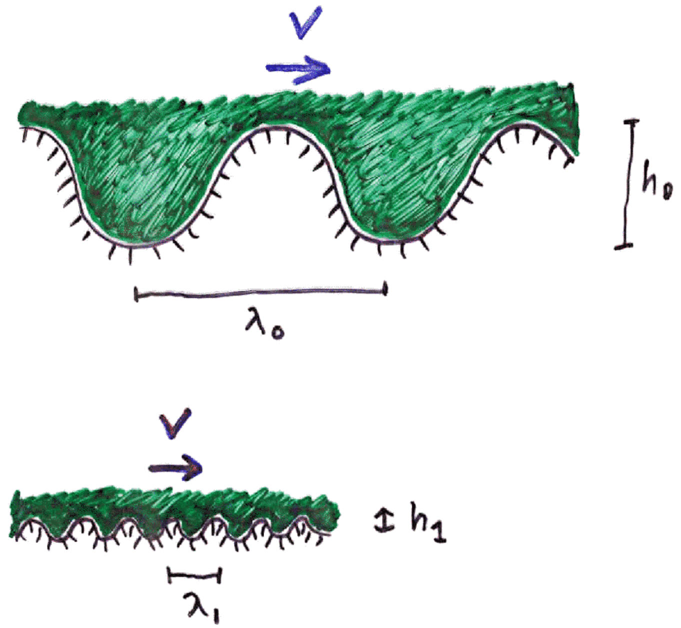
- Schallamach waves (elastic instability)

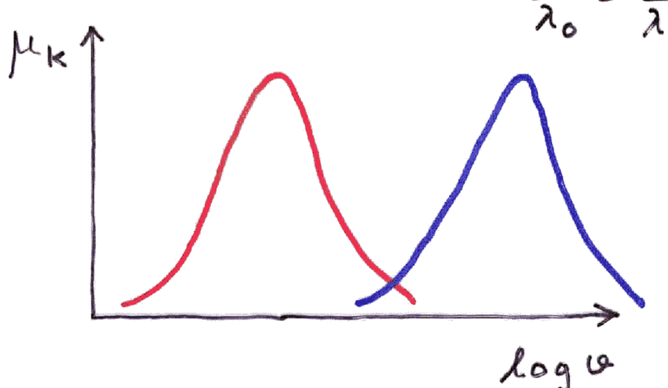


- Shearing contamination layer:

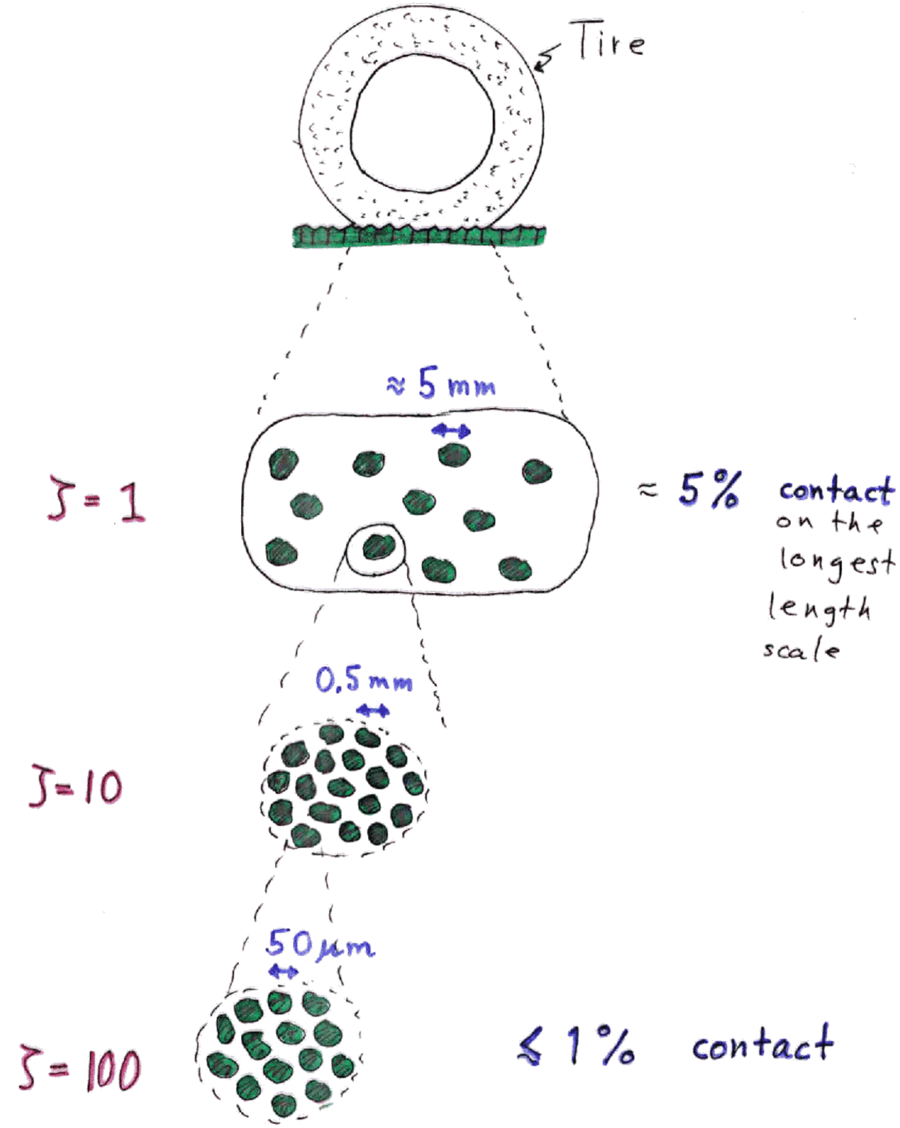








Surface roughness of different



$$C(q) = \int d^2x \, \langle h(x) h(0) \rangle e^{i q \cdot x}$$

$$\mu = \frac{1}{2} \int dq \; q^3 \; C(q) P(q) \; \int_0^{2\pi} d\phi \; \cos\phi \; \mathrm{Im} \frac{E(qv\cos\phi)}{(1+\nu)(1-\nu)\sigma_0}$$

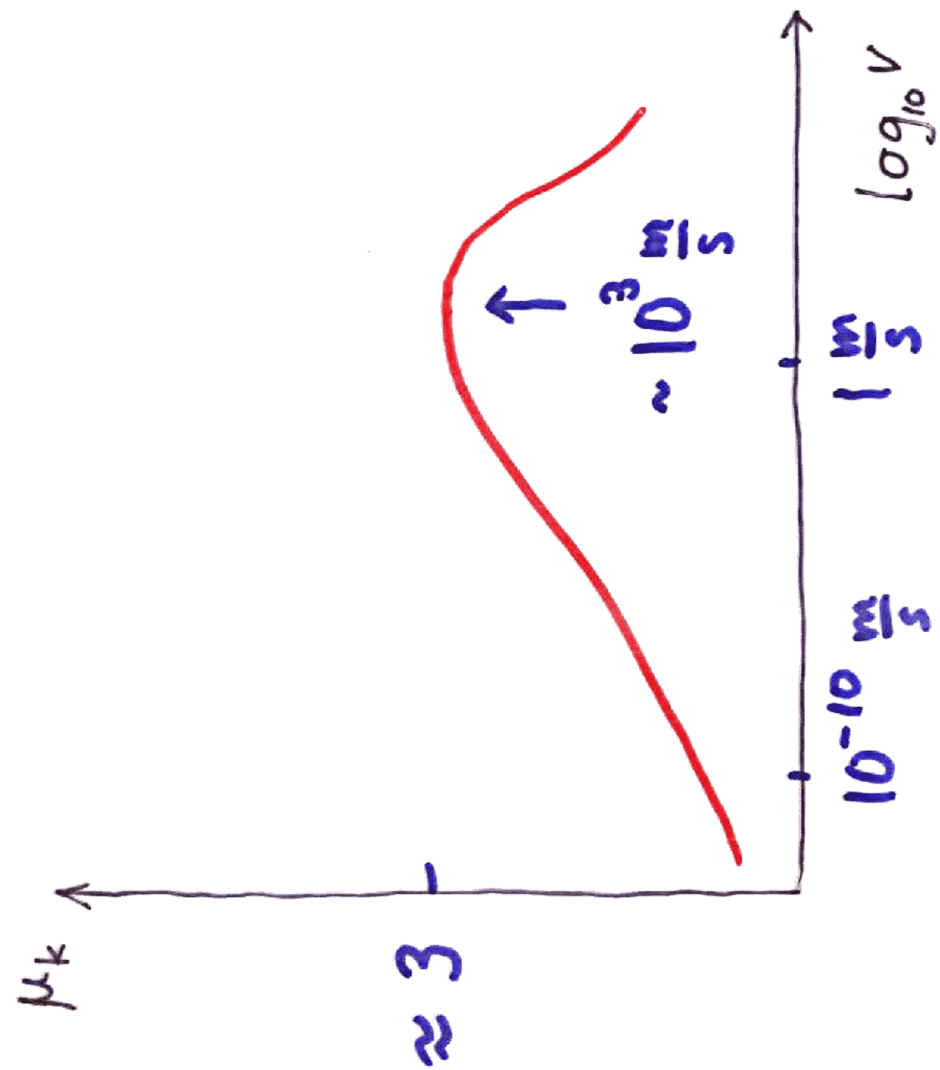
$$P(q) = \frac{2}{\pi} \int_0^\infty dx \; \frac{\sin x}{x} \; \exp\left[-x^2 G(q)\right]$$

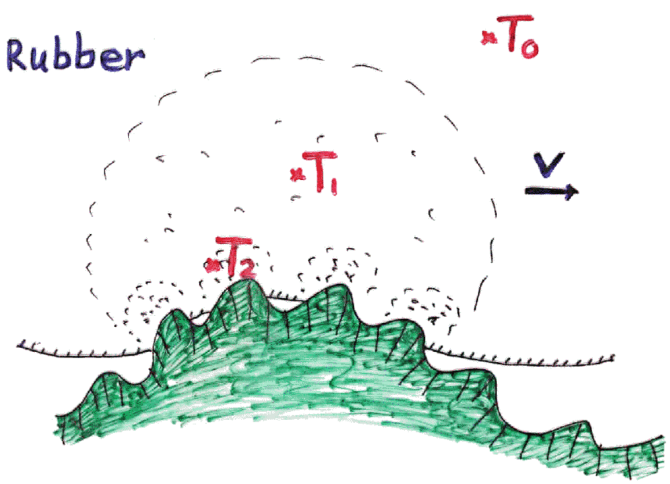
$$G(q) = \frac{1}{8} \int_{q_0}^{q} dq \; q^3 C(q) \int_0^{2\pi} d\phi \; \left| \frac{E(qv\cos\phi)}{\sigma_0(1-\nu^2)} \right|^2$$

When $\sigma_0 \ll E(0) \Rightarrow$

$$P(q) \approx \int_0^\infty dx \; \exp\left[-x^2 G(q)\right] = [\pi G(q)]^{-1/2}$$

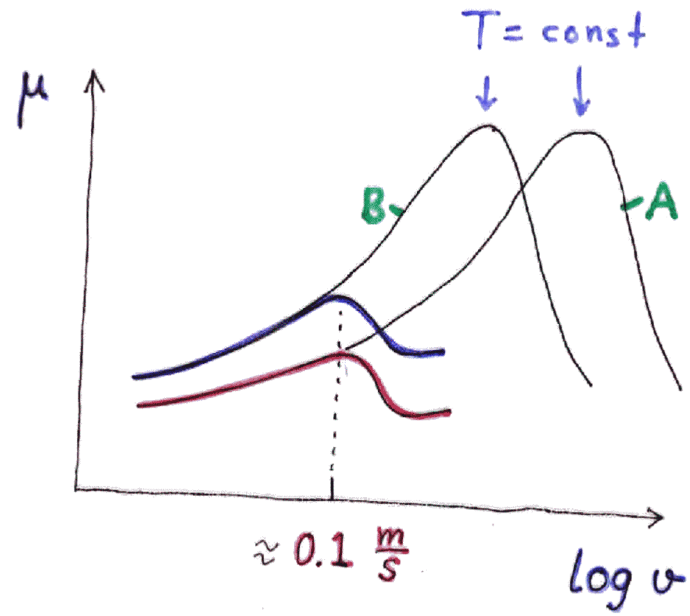
$\Rightarrow$ μ independent of σ_0



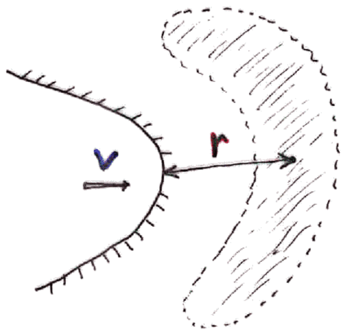


Flash temperature

$T_0 < T_1 < T_2$



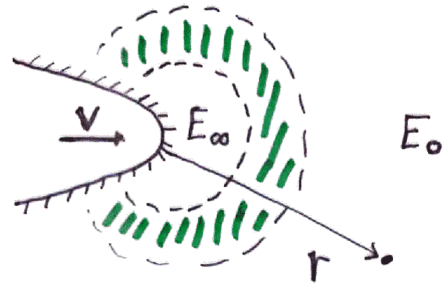
Flash-temperature fundamental for ABS-breaking and non-stationary sliding!



$$\omega_1 \approx \frac{v}{r}$$

$$G(v) = G_0 \left[1 + f(v) \right]$$

$$\frac{G}{G_0} = 1 - \frac{2}{\pi} E_0 \int_0^{2\pi v/a} d\omega \, \frac{F(\omega)}{\omega} \, \mathrm{Im} \frac{1}{E(\omega)}$$



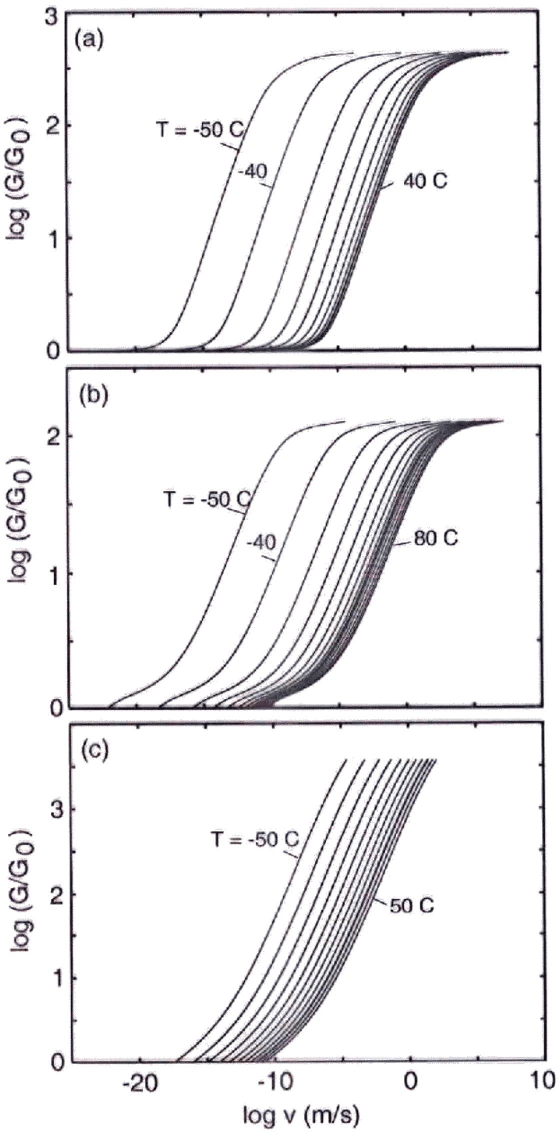
$$\omega \sim \frac{v}{r}$$

$$\sigma \sim \frac{K}{\sqrt{r}}$$

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

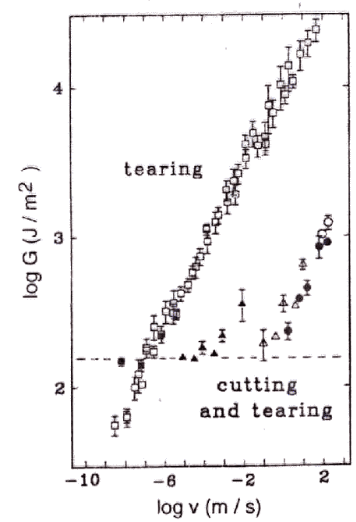
$$G_0 = \frac{K^2}{E_\infty}$$

$$G = \frac{K^2}{E_0} = \frac{E_\infty}{E_0} G_0$$

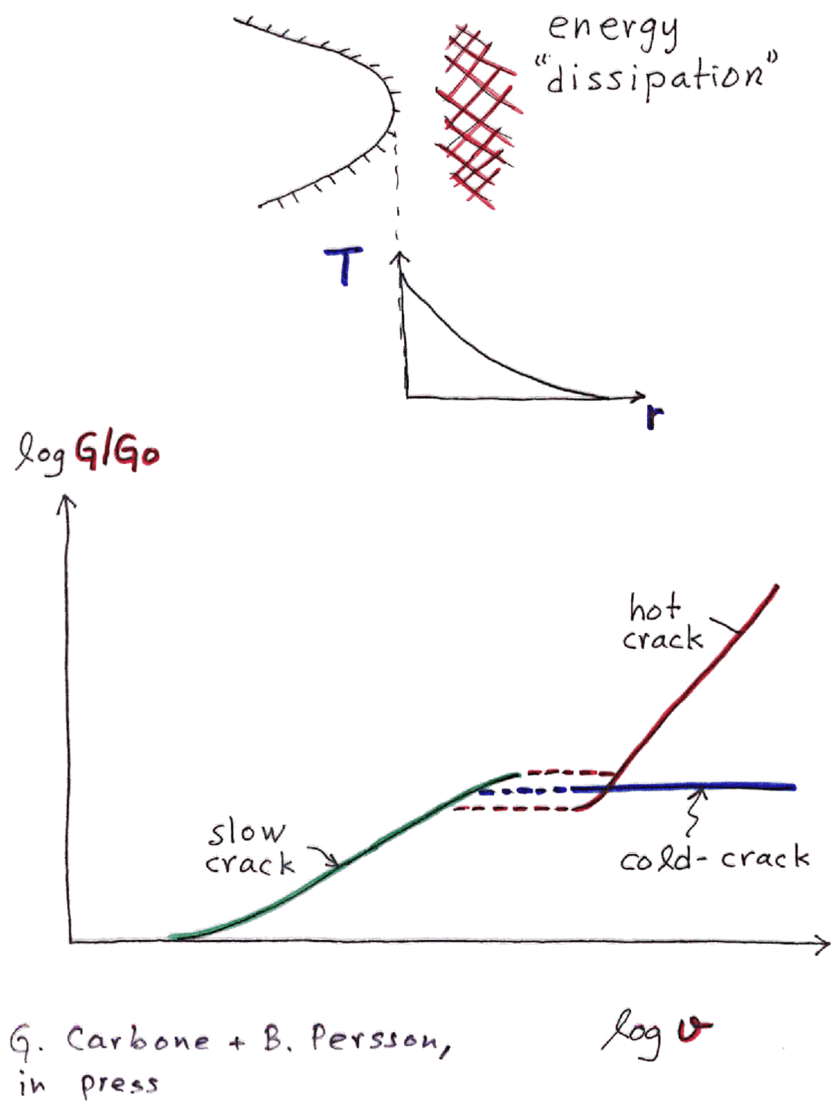


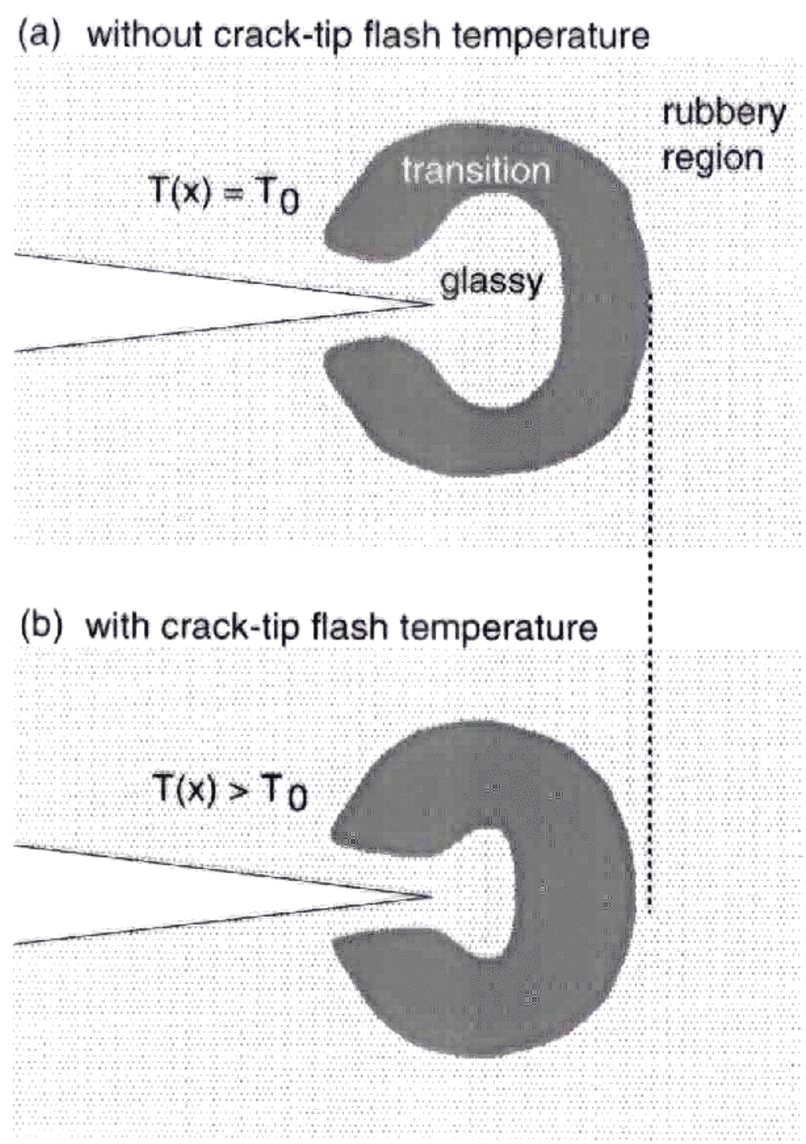
$G \approx v^{\alpha}$

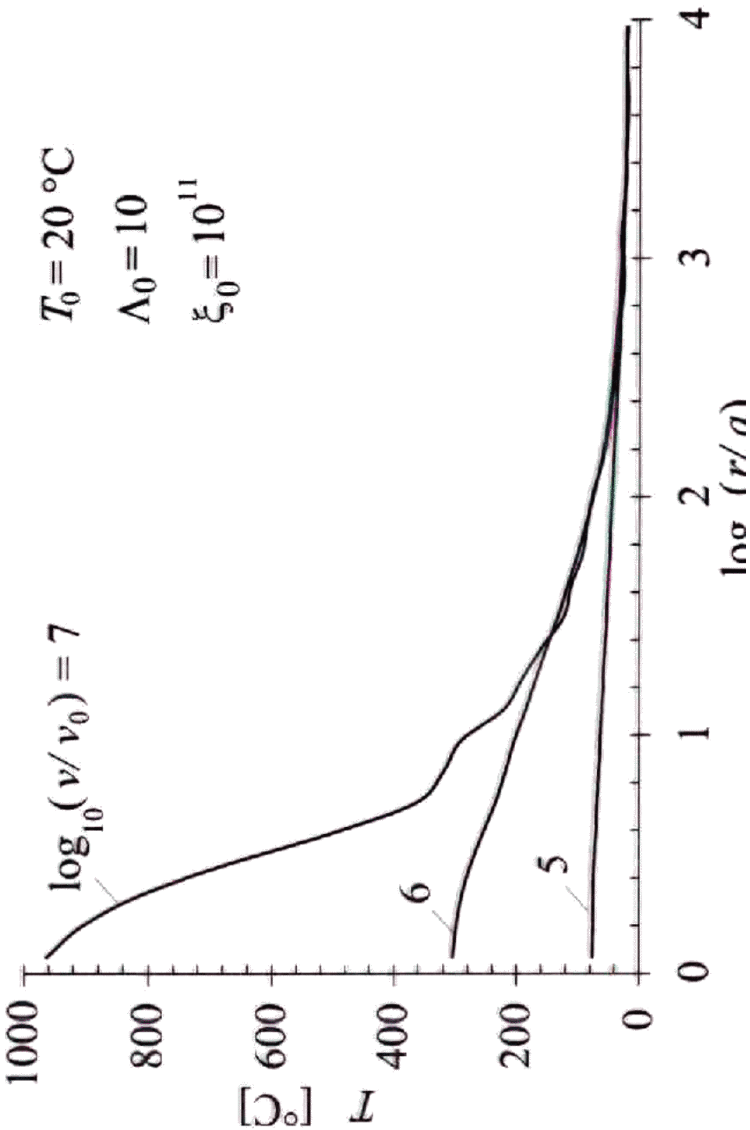
$\alpha \approx 0.3$

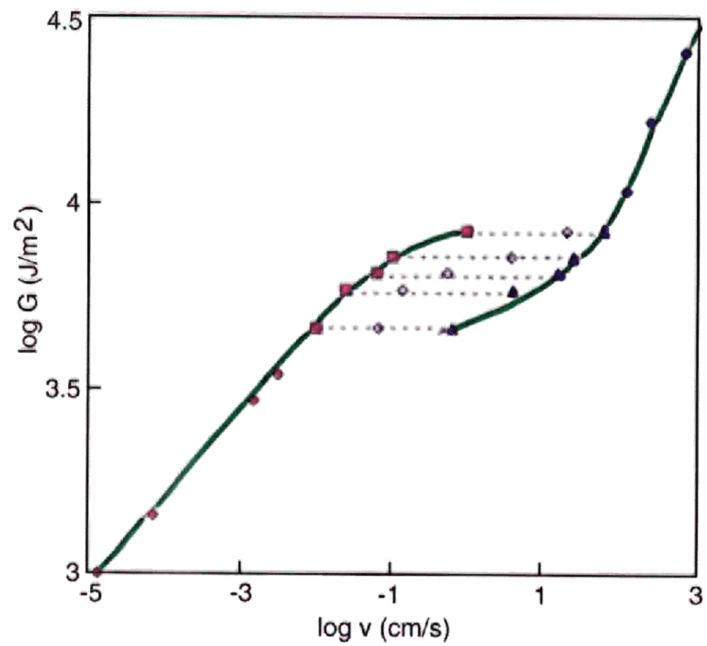


Gent et.al.

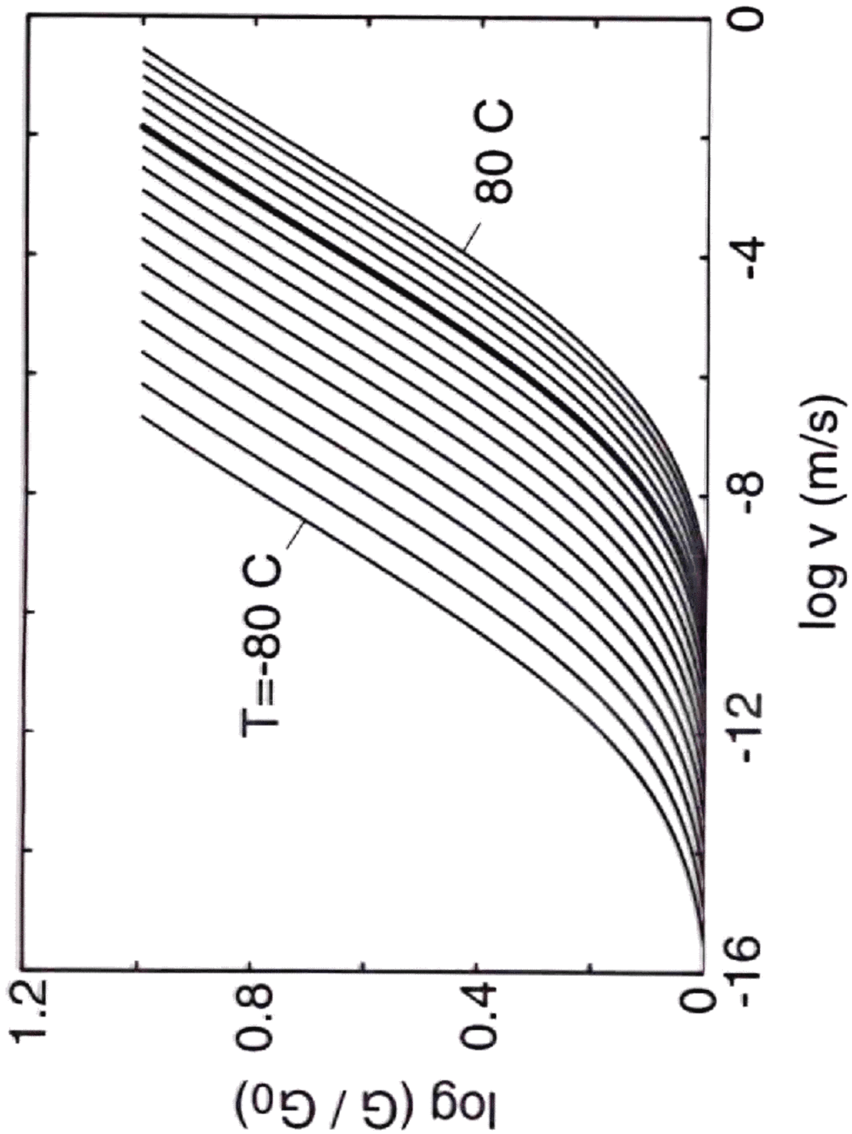

energy
"dissipation"
T
r
log G/G0
hot
crack
slow
crack
cold-crack
log v
G. Carbone + B. Persson,
in press

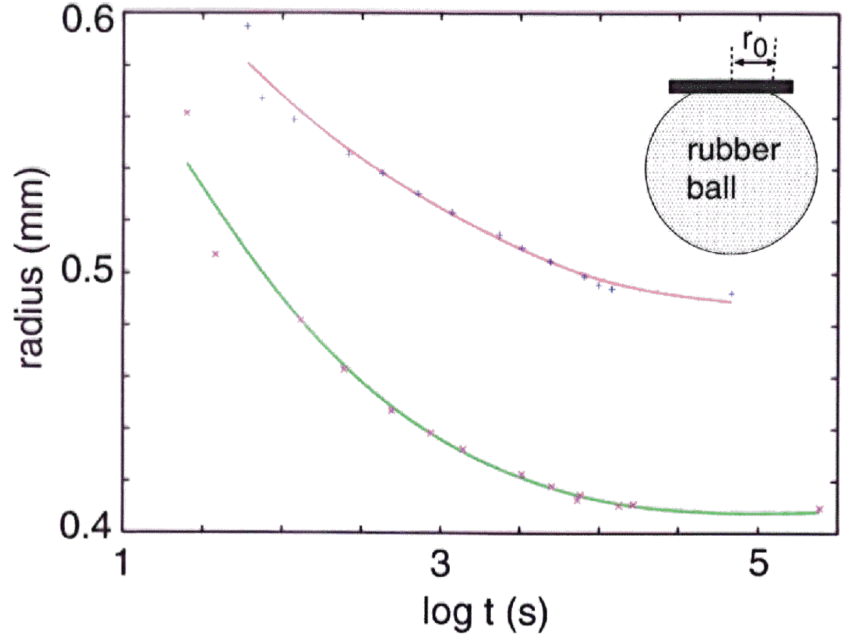

(a) without crack-tip flash temperature
rubbery
region
transition
T(x) = T0
glassy
(b) with crack-tip flash temperature
T(x) > T0

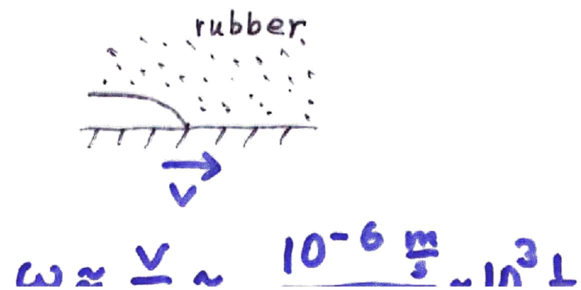


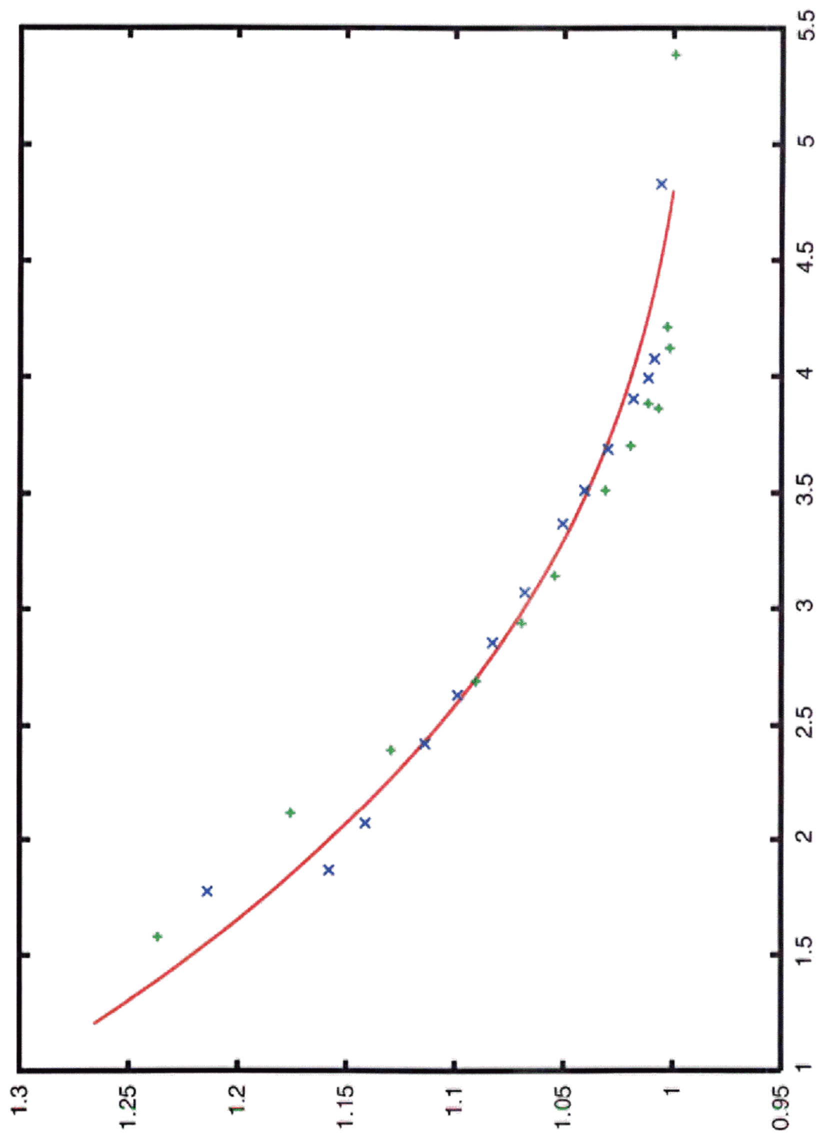


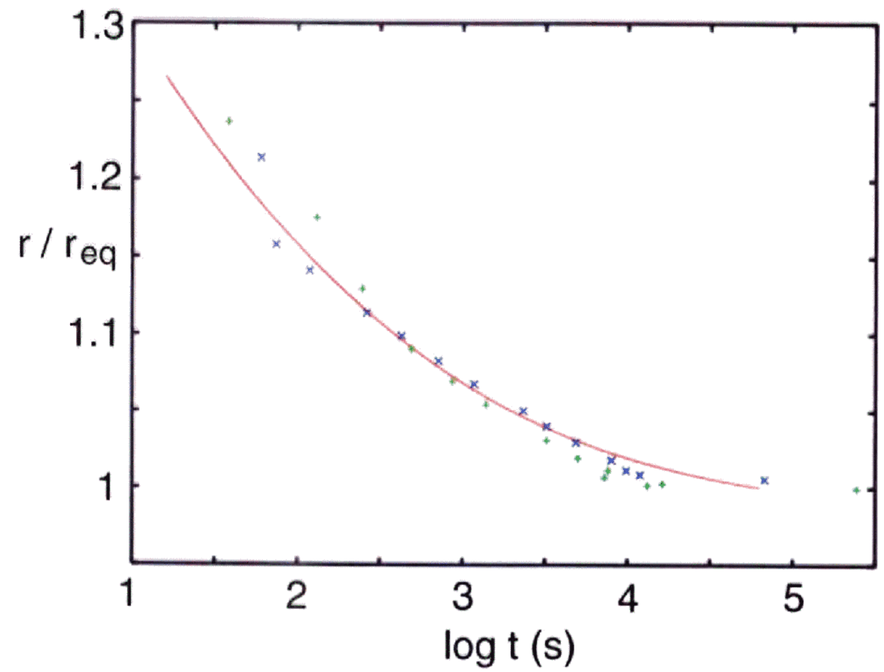
Tsunoda, Busfield, Davies, A.G. Thomas
J. Materials Science 35, 5187 (2000)

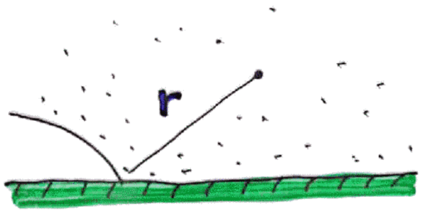

log (G / G0)
log v (m/s)
T=-80 C
80 C
1.2
0.8
0.4
0
-16
-12
-8
-4
0


radius (mm)
log t (s)
rubber ball
r0
0.6
0.5
0.4
1
3
5


rubber
v


1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5


1.3
1.2
1.1
1
r / r_{eq}
1
2
3
4
5
log t (s)



$$\sigma \sim \frac{1}{\sqrt{\mathbf{r}}}$$

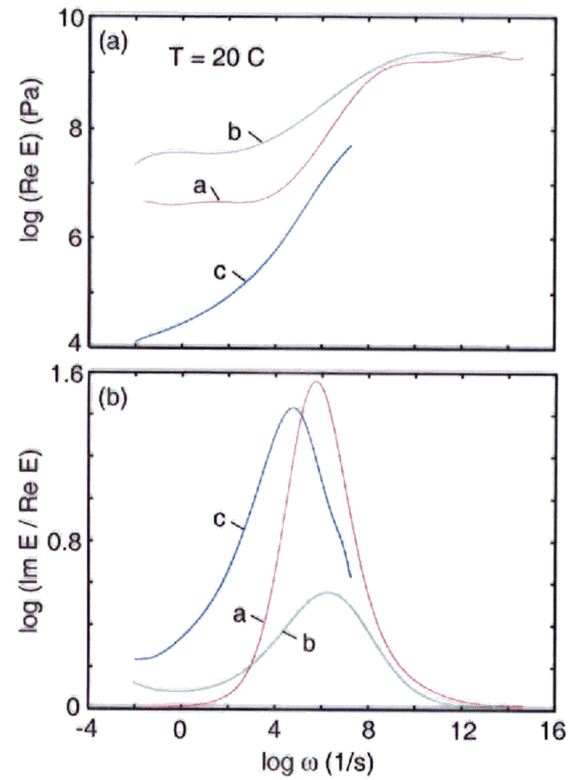
$$\dot{E} \sim \int d^2x \; \sigma \cdot \dot{\epsilon}$$

$$\sim \int d\mathbf{r} \; \mathbf{r} \frac{1}{\sqrt{\mathbf{r}}} \underbrace{\frac{d}{dt} \frac{1}{\sqrt{\mathbf{r}}}}_{\frac{v}{\mathbf{r}^{3/2}}}$$

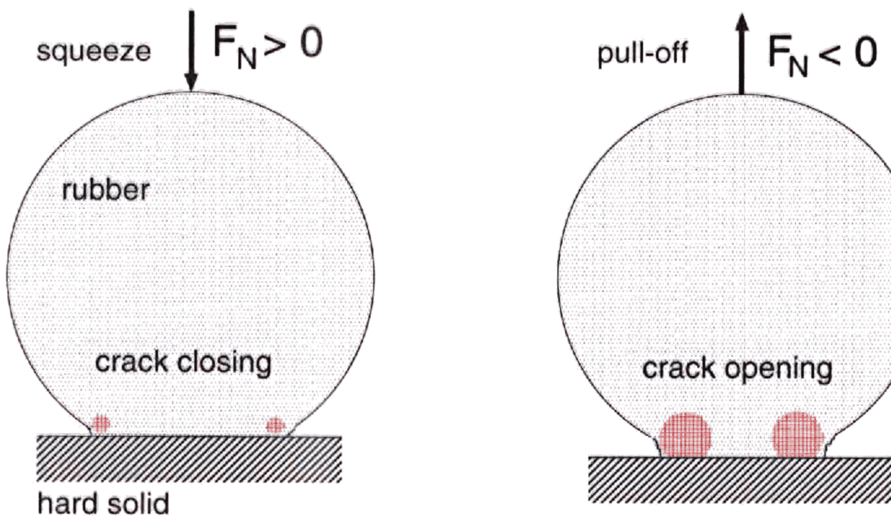
$$\sim \int d\mathbf{r} \; \mathbf{r}^{-1} \sim \ln \mathbf{r}$$

$$\rightarrow \infty \quad \text{as} \quad \mathbf{r} \rightarrow 0$$

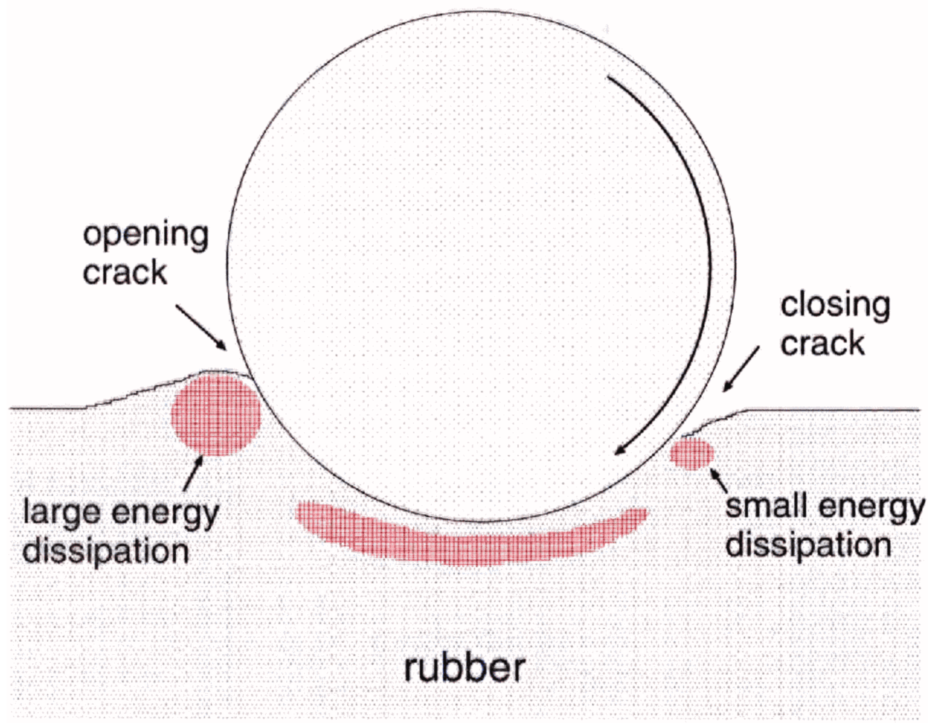
Huge "dissipation" of energy close to the crack-tip!



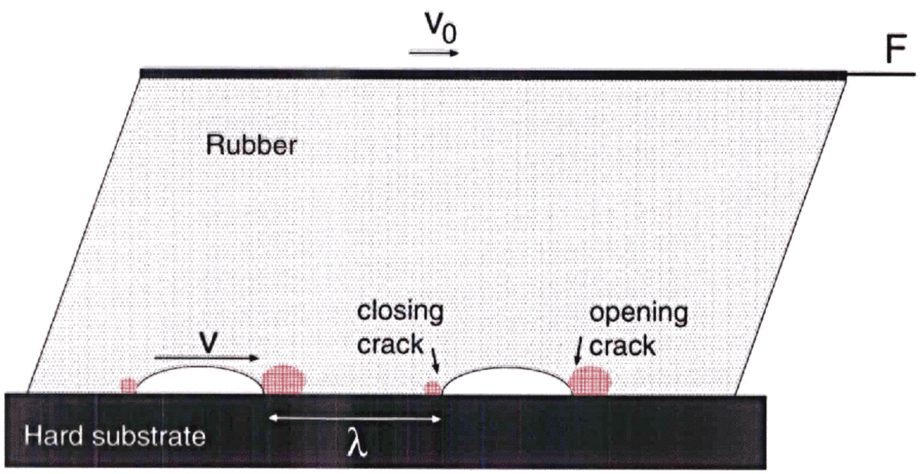
Squeeze and Pull-Off



Rolling cylinder



Rubber Friction on Smooth substrate



A.D. Roberts and A.G. Thomas,
Wear 33, 45 (1975)

Rubber Friction on Smooth Wavy Substra