Bo Persson

Research Center Juelich
Germany

Surface roughness

Contact mechanics

Adhesion

Crack propagation in rubber

Rubber friction

Diamond friction

Ultra-high vacuum

\( \mu \sim 10 \)

passivated surfaces

\( \mu \sim 0.01 \)

Elastic instability:

Elastically soft

hard
Many length scales:

$\xi = 100$

$\xi = 10$

$\xi = 1$

Surface roughness power spectra $C(q)$

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

Log-log plot of $C(q)$ vs. $q$ for asphalt and surface 1.
Viscoelastic Modulus $E(\omega)$

- Rubbery region
- Transition region
- Glassy region

Overview of Rubber friction processes

- Hysteric contribution:

  $\omega = \frac{v}{l}$

- Adhesion contribution:

  Schallamach:

  Persson:

  The same temperature dependence as that of the complex elastic
• Schallamach waves (elastic instability)

\[ \text{detachment wave} \]

• Shearing contamination layer:

\[ \text{organic contamination} \]
\[ C(q) = \int dq \langle h(x) h(z) \rangle e^{i q \cdot \mathbf{x}} \]

\[ \mu = \frac{1}{2} \int dq \, q^3 \, C(q) \, P(q) \int_0^{2\pi} d\phi \cos \phi \, \text{Im} \frac{E(q \cos \phi)}{(1 + \nu)(1 - \nu)s_0} \]

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

\[ G(q) = \frac{1}{8} \int_{q_0}^q dq \, q^3 C(q) \int_0^{2\pi} d\phi \frac{E(q \cos \phi)}{s_0(1 - \nu^2)} \left| \frac{E(q \cos \phi)}{s_0(1 - \nu^2)} \right| \]

When \( s_0 \ll E(0) \)

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

\( \Rightarrow \mu \) independent of \( s_0 \)
Flash temperature

\[ T_0 < T_1 < T_2 \]

Flash-temperature fundamental for ABS-breaking and non-stationary sliding!
\[ \omega_1 = \frac{v}{r} \]

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

\[ \frac{G}{G_0} = 1 - \frac{2}{\pi} \frac{a}{\omega_0} \int_0^{2\pi} \frac{F(\omega)}{\omega} Im \frac{1}{E(\omega)} \]
\[ \sigma \approx v^\alpha \]

\[ \alpha \approx 0.3 \]
\[ T_0 = 20^\circ C \]
\[ A_0 = 10 \]
\[ \xi_0 = 10^{11} \]

\[ \log_{10}(\psi/\psi_0) = 7 \]

\[ \log_{10}(v/v_0) = \]

\[ [\psi_0] \quad I \]

\[ \log G (J/m^2) \]

\[ \log v (cm/s) \]

Tsunoda, Busfield, Davies, A.G. Thomas
Bo Persson, Juelich (KITP Earthquake Conference 8-18-05) Rubber Friction and Crack Propagation in Rubber-like Materials

---

The image contains two graphs and a set of mathematical equations.

1. The left graph shows a set of curves labeled with temperatures (T) ranging from -80°C to 80°C. The y-axis is labeled \( \log v \) (m/s) and the x-axis is labeled \( \log (C/G) \) with values ranging from 0.2 to 1.8.

2. The right graph plots the radius (mm) against log time (s). The radius values range from 0.4 to 0.6 mm, and the time values range from 1 to 5 s.

3. Below the graphs, there is a mathematical equation: \( \omega \approx V \approx 10^{-6} \ m/s \).
\[ \sigma \sim \frac{1}{\sqrt{r}} \]

\[ \dot{E} \sim \int d^2 \sigma \cdot \dot{\varepsilon} \]

\[ \sim \int d^2 r \frac{1}{\sqrt{r}} \frac{d}{dt} \frac{1}{\sqrt{r}} \]

\[ \sim \int d^2 r \frac{1}{r^{3/2}} \sim \ln r \]

\[ \rightarrow \infty \text{ as } r \rightarrow 0 \]

"dissipation" of energy

Huge \textit{dissipation} of energy

\textit{...at the crack-tip...}
Squeeze and Pull-Off

squeeze $F_N > 0$

rubber

crack closing

hard solid

pull-off $F_N < 0$

rubber

crack opening

Rolling cylinder

opening crack

large energy dissipation

closing crack

small energy dissipation
Rubber Friction on Smooth Substrate

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