Transient and steady-state features of anisotropic friction forces

Jacob Israelachvili, Kai Kristiansen, Xavier Banquy, Jing Yu, Saurabh Das, Sathya Chary, John Temelier & Kim Turner (UCSB)

Hongbo Zeng (Alberta)

Eric Charrault & Suzanne Giasson (Montreal)
What needs to be measured in a complete friction experiment

Also: Surface structure (roughness, topology), transient, time-dependent vs steady-state effects, e.g., stick-slip, …
Surface Forces Apparatus (SFA 2000)

Shearing attachments to the SFA
FECO fringes of two curved surfaces close together

FECO (right) and normal microscope view (left) of the two surfaces in flattened adhesive contact

FECO and microscope views of a liquid bridge/neck
Adhesion-controlled and load-controlled friction forces by SFA

![Graph showing friction force and contact area as a function of load.](image)

Adhesion- and load-controlled friction forces by AFM
Viscous-controlled friction forces …. also, a good way to introduce anisotropic friction
XYZ actuator-sensor for the SFA 2000 (3D SFA)
Anisotropic lubricant fluid: \textit{n}-hexadecane between mica

Shear-induced ordering of \textit{n}-eicosane previously shown by Drummond \textit{et al.}, PRE \textbf{66} (2002) 011705, and others.
Friction of hexadecane films: details of the on- and off-axis friction forces and displacements during back and forth sliding

- Twist angle \( \theta = 0° \).
- Applied force angle \( \psi = 0° \).
- Load 6 mN (No. of layers: 5?).
- Sliding velocity \( v_a = 5.1 \ \mu \text{m/s} \).

Shear-induced ordering of hexadecane gives anisotropic friction forces and off-axis relative surface displacements.

Note long transient (distance).
Friction ‘limit cycles’ of hexadecane films

- Limit cycles of: (a) the total friction force, and (b) absolute relative surface velocity.
- **Red path** shows smooth, linear, isotropic Amontons-like sliding cycle (no off-axis displacement), shown for comparison.
- **Note:** displacement and velocity change smoothly at the (discontinuous) changes in the sliding direction.
- Mica configurations with other twist angles and applied force angles also give off-axis motions.
Friction of squalane – a highly branched alkane

- Load 3 mN,
- Velocity $v_a = 2 \mu m/s$,
- Twist angle $\theta = 0^\circ$,
- Applied force at $\psi = 0^\circ$,

$\Rightarrow F_{\parallel} \approx 0$: No off-axis friction forces or motions measured.
Anisotropically structured (polymer) surfaces: fabricated PDMS tilted micro-flaps ....

Tilted PDMS micro-flaps
…. sliding against: smooth and rough glass surfaces

RMS = 11±8 nm
RMS = 72±35 nm
RMS = 140±100 nm
RMS = 180±150 nm
RMS = 350±300 nm
Adhesion and friction against smooth (11 nm) glass

Friction

Adhesion measured after shearing
Adhesion and friction against rough glass

Friction →

Adhesion →

+\( y \) direction

\[ \text{Friction force, } F_{||} \text{ (mN)} \]

\[ \text{Normal force, } F_{\perp} \text{ (mN)} \]

-\( y \) direction

\[ \text{Friction force, } F_{||} \text{ (mN)} \]

\[ \text{Normal force, } F_{\perp} \text{ (mN)} \]