Origins of roughness evolution

and strategies for its implementation on rate-state faults

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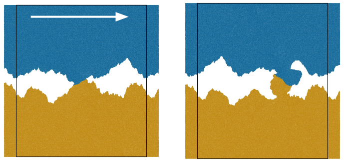
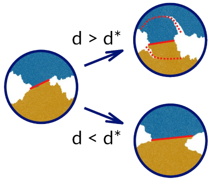
Onset of wear: debris formation

Inspired by the recent finding of a critical length scale *d** that governs the ductile-to-brittle transition in adhesive wear [1], we performed **long-timescale 2D atomistic simulations of rough, sliding surfaces** [2,3].

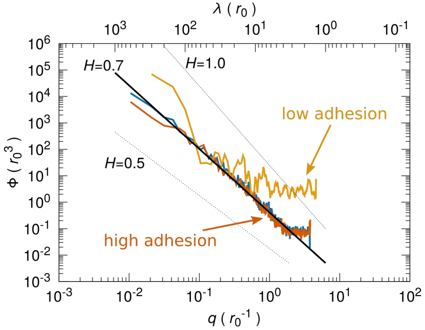




The aforementioned critical length scale separates two distinct mechanisms upon asperity collision: ductile smoothing if the junction size *d* is smaller than *d**, brittle fracture and debris formation if larger. Our simulations are run in the latter condition, such that a debris particle is always formed, and rolls between the surfaces, wearing them off and progressively growing in size.

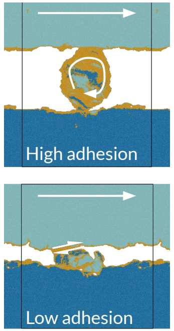
Self-affinity of run-in surfaces

Surface analysis was performed whenever the surfaces, after a running-in period, reached a steady-state for the root-mean-square roughness. Different initial surface conditions always lead to self-affine morphologies with the same Hurst exponent [2], with one exception: low interfacial adhesion [3] (see differences in the power spectral density ϕ on the right).



If the adhesive forces between atoms belonging to a free surface are low compared to their cohesion within the bulk, the fractal morphology can be inhibited.

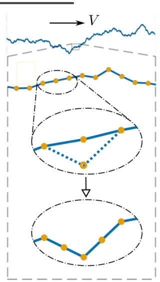
Life of a debris particle



If the interfacial adhesion is high, the debris particle grows into a final shape that is generally rough but convex and close to circular. The particle then continuously rolls between the surfaces and exchanges materials with them, leading to a smooth evolution of surface properties and low frictional force [2].

If the interfacial adhesion is low, the particle tends to stick to one surface (sliding against the other), not exchanging much material in the process. As a result, the surfaces do not evolve into the self-affine morphology [3].

The particular stress state at the interface between the debris particle and the surfaces drives the overall growth of the particle [4], which is responsible for the roughening the surfaces [2,3].



Outlook: rate-state faults

The aforementioned observations are the basis for ongoing work on the effects of roughness evolution in rate-state faults. A roughening mechanism is being implemented in a quasi-dynamic boundary element code [5], which will allow to study the effects of roughness changes during cycles of earthquakes.

Conclusions

- Numerical simulations successfully reproduced the **self-affine morphology of worn surfaces**.
- The surfaces roughness is characterized by a **Hurst exponent H = 0.6–0.8, consistent with experimental data**.
- **Low interfacial adhesion** inhibits the development of said self-affine morphology.
- **Third body modelling is necessary** to capture the roughness evolution.

References

[1] Aghababaei, Warner, Molinari, *Nat. Commun.*, **7**, 1-8 (2016)
[2] Milanese, Brink, Aghababaei, Molinari, *Nat. Commun.*, **10**, 1-9 (2019)
[3] Milanese, Brink, Aghababaei, Molinari, *Phys. Rev. E*, **102**, 043001 (2020)
[4] Milanese, Molinari, *Int. J. Solids Struct.*, **203**, 1-16 (2020)
[5] Segall, Bradley, *Geophys. Res. Lett.*, **39** (2012)