Critical flow properties of a frictional interface

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Quasi-statically sliding a solid block over a nominally flat surface proceeds by stick slip: macroscopic slip events are punctuated by periods of loading. We identify how macroscopic slip is nucleated by collective asperity detachments. This insight allows us to make a prediction for the stress at which macroscopic slip is nucleated (1). Quasi-static sliding in the thermodynamic limit proceeds at a stress σ_c whereas in a finite system, events are rare, causing stress to build-up at a stress $\sigma_n > \sigma_c$. In this talk, we push on to identify σ_c as the minimum of the interface's effective flow curve. The corresponding finite slip rate is rationalised by a newly identified scaling relation, as follows.

We propose a model that includes asperity-level disorder, elastic interaction between local slip events, and inertia. Thereto we model the frictional interface as a continuum in which the asperity contacts are modelled using 'blocks' that represent one or several asperity contacts. Each block thereby responds elastically up to a yield stress, upon which it releases part of its built-up elastic energy. As the blocks model a sequence of asperity contacts, each time with a different strength, the yield stresses a drawn randomly from some distribution.

We identify a non-monotonic effective flow curve that is decomposed as follows. The interface itself is unstable: blocks are effectively weaker in the presence of mechanical noise (that acts as a sort of temperature), while the amount of noise increases with the rate of activity. This flow curve is well-fitted using a commonly used phenomenological macroscopic friction law $\sigma \sim -\ln v$ (without such behaviour being assumed microscopically), where σ is the stress and v is the slip rate. The interface is stabilised by dissipation, leading to an effective flow curve (2). During steady-state flow, the dissipation comes fully from friction. During the nucleation of flow, however, the interface experiences effective dissipation through the energy spent on the acceleration of the bulk material around the propagating 'fracture' (2, 3), leading to an effective flow curve $\sigma \sim v - \ln v$, that has a minimum that we denote σ_c (with a corresponding finite slip rate v_c).

We find that σ_c is a critical point for the dynamics of the frictional interface. When the system is loaded quasi-statistically at σ_c, the system displays avalanches of 'asperity detachments' whose size, radius, and duration are power law distributed. This fact allows us to identify a new scaling relation for friction that confirms that the slip rate, $v_c \equiv v(\sigma_c)$, is finite and independent of the avalanche radius

Avalanches of 'asperity' detachements a not very frequent in a finite system, allowing the system to build up stress beyond σ_c: a finite system displays stick slip, whereby σ_c is the average stress after slip events. Nucleation of these slips is governed by a fracture-like instability as follows. Inside an avalanche the stress dynamically drops to σ_c, the avalanche therefore acts as a scar in the material. Following Griffith's stability criterion for fracture, the scar is unstable if its radius is bigger than $A_c \sim (\sigma - \sigma_c)^{-2}$. When this happens, is finally governed by the rate of avalanches, which is determined by the distribution of barriers after a slip event, whose distribution is empirically found to display a so-called pseudo-gap (the distribution follows a power law $P(x_\sigma) \sim (x_\sigma)^\theta$ at small argument, with x_σ that is needed to yield a block locally). This characteristic (1) leads us to conclude that stick slip is finite size effect, and allows us to predict the stick-slip amplitude as a function of the system size.

Finally, when the system is driven at a stress $\sigma < \sigma_c$, which can occur for example when the system is thermally relaxed after a slip event, the avalanches are cut off by the disorder, and therefore nucleation of slip cannot occur in this case.

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