Contact mechanics for randomly rough surfaces
Author: B. N. J. Persson
http:arXiv.org/cond-mat/0603807

Recommended with a commentary by Wim van Saarloos, Leiden University

We are so used to the existence of friction between macroscopic objects, that we often forget that there are many intriguing questions concerning the origin of friction [1]. For instance, when a macroscopic object slides over a flat surface, the standard Coulomb friction law known to most physicists is that the friction force is simply proportional to the weight of the sliding object or to the pressure exerted on the sliding object, with a proportionality factor that is characteristic of the material. Why doesn't the macroscopic surface area A_0 of the sliding surface come in? In other words, why do two blocks of the same weight and material but with different aspect ratios experience the same sliding friction according to this classical friction law? Is it true, as this law suggest, that the friction force is independent of the sliding speed? Also, if the block is not sliding, is there really a single static friction coefficient, or is the thres-hold stress beyond which sliding occurs actually time-dependent due to, e.g., aging effects?

In recent years there has been quite some progress, both theoretically and experimentally, on these issues. For instance, careful measurements of dry friction as a function of the velocity of the contact by a group in Paris has revealed a slow (logarithmic) increase of the friction with speed, while the static threshold is found to increase slowly with the time the contact has been at rest [2]. The paper *Contact mechanics for randomly rough surfaces* by Persson was stimulated by recent experimental findings by the same group [3] on the sliding friction of a very smooth glassy polymer lens past a flat silica surface, which showed that the friction force was not proportional to the pressure on the lense — instead it increased slower than linearly with pressure.

The picture underlying dry friction of hard solids is that the contact surface in reality consists of multicontact interfaces associated with the asparities of the rough surfaces. When two surfaces are pressed only gently against each other, a few asparities touch, and the nominal area of contact A is much less than the macroscopic surface area A_0: $A \ll A_0$. In this limit there is only contact on relatively small scales. As the surfaces are pressed harder against each other, the contacting asparities are increasingly deformed: they gro w in size, while new contacts are formed. The scenario Persson argues for is that when the pressure increases and A becomes of order A_0, a type of fractal picture emerges, with bumps and partial contacts on many different length scales. Viewed this way, the challenge is to derive a friction law from the roughness of the interface, which is characterized statistically by the height-height correlation function, and the response of a given asperity to a compression force.

Older theories of contact mechanics of rough surfaces are indeed usually based on roughness on a single length scale, and so are limited to the regime $A \ll A_0$; the stress-induced interaction between different asparities can then be neglected. As discussed by Persson, in this limit the linear friction law (friction force proportional to the pressure or the normal force) does arise. Persson however develops an approach which is able to handle the crossover to the large pressure regime where $A = \mathcal{O}(A_0)$ where roughness and contacts over a large range of length scales are important. The input to the theory is the roughness correlation function of original interface.

In applying his theory to the experiments on the sliding glassy lense, Persson estimates the roughness correlation function from the capillary waves, frozen in at the glass temperature $T_g \approx 100\ ^oC$, as the lenses were formed by cooling a liquid drop of the polymer material from 250 ^oC to room temperature. The nonlinear friction curve he then finds does fit the experimental data of [3] remarkably well.

These results are a strong indication that as the pressure on a sliding contact is increased, contacts on a range of scales start to become important. The paper also has a nice discussion of nature's solution to strong adhesion, so that insects can walk on a vertical wall. For an elastic material to adhere to a rigid rough surface, the elastic modulus must be small enough. Sometimes nature does this by using foam or fiber-like structures made of intrinsically stiff materials.

References:

1. B. N. J. Persson, *Sliding friction: Physical Principles and Applications* (Springer, Heidelberg, 2000).

2. L. Bureau, T. Baumberger and C. Caroli, *Rheological aging and rejuvenation in solid friction contacts*, Eur. J. Phys. E **8**, 331 (2002).

3. L. Bureau, T. Baumberger and C. Caroli, *Non-Amonton behavior of friction in single contacts*, cond-mat/0510232.