RATE AND STATE FRICTION LAWS MEASURED IN SILICA NANOCONTACTS WITH AN ATOMIC FORCE MICROSCOPE

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Frictional forces play a mayor role in the dynamics of many solid systems studied in different sciences, from the movement of geeko lizzards in biology and mechanical engines in ingenering to tectonic motion in geophysics [1]. In any case, independently of the spatial scales involved, frictional forces are considered as effective surface forces which depend on a wide variety of parameters. For example, the roughness and temperature of the interface, the elasticity and hardness of the materials in contact, and the normal and adhesion forces which keep the surfaces together. Nevertheless, a series of friction experiments at low velocities on different macroscopic solids, including metal, paper, wood, plastics, a variety of rocks and gauge, have been shown to be described by a set of phenomenological laws named the rate and state-dependent friction laws (RSF) [1-2]. These laws also explain very well some key features of the dynamics of tectonic faults [1]. This has motivated the study of a common physical description of frictional processes, independent of the microscopic details of the specific system under study. In this sense, it is important to determine the range of scales where the RSF laws can be applied and ultimately determine the physical interpretation of the parameters involved. In this work we measure the friction force between a nanometer sized Silicon Nitride tip and a Silicon wafer with a comercial Atomic Force Microscope (AFM) in ambient conditions. The tip is mounted on a cantilever and its movement is controlled by a Lead Zirconate Titanate piezoceramic actuator (see Fig 1). To perform friction tests, we apply an external signal to the piezoelectric and force the cantilever to slide at constant velocity, following different protocols and always in the direction perpendicular to the cantilever's principal axis. In this way, the cantilever twists to balance the friction force at the tip appex. Therefore the cantilever's deflection is a measure of the external driving force which is obtained by pointing a laser beam at the cantilever and sensing the reflected signal with a photodetector. We conduct slide-hold-slide experiments where we measure the static force that is needed to restart motion as function of both the time that it has been hold and the loading velocity (see Figs. 2-3). We also measure the friction force as function of the sliding velocity, both in the steady state and when a velocity step is applied. We find that our results at the nanoscale are in good cualitative agreement with the phenomenological rate and state friction laws usually used to describe the main dynamical properties of frictional interfaces at the macroscale. This shows the existance of an aging mechanism and a direct velocity effect present at multicontact interfaces at the nanoscale. The former is believed to be originated in the formation of chemical bonds between the tip and the substrate [3] and the later is most likely due to temperature fluctuations which enhaces the probability of the tip to slide at lower velocities [2]. The competition between these two effects determines wether the steady state sliding friction force increases or decreases as function of sliding velocity. When the aging mechanism is strong enough, and therefore friction decreases with velocity, time-controlled "stick-slip" motion may be observed. We indeed observe such intermitent dynamics at the nanoscale (see Fig. 4), which is of different origin from the stick-slip motion previously reported in the literature which is due to the topography of the substrate.

REFERENCIAS

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[3] Li Q., Tullis T.,Goldsby D., and Carpick R., (2011) "Frictional ageing from interfacial bonding and the origins of rate and state friction", *Nature* 480: 233-236.

AGRADECIMIENTOS

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FIGURAS

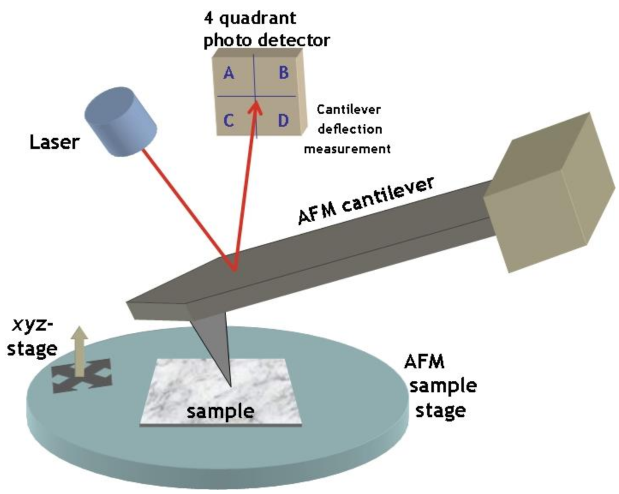

Figura 1. Sketch of the experimental configuration. We always move in the direction perpendicular to the cantilever's principal axis. In this way, the lateral deflection of the cantilever measures the friction force between the tip and the substrate. (From https://simple.wikipedia.org/wiki/Atomic_force_microscope).

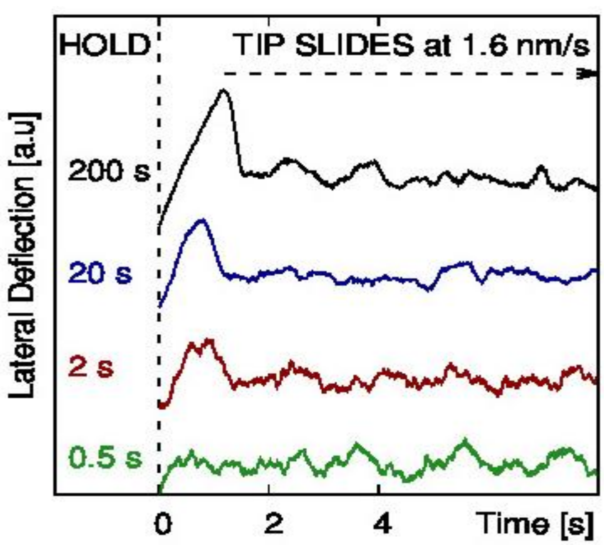

Figura 2. Lateral deflection of the cantilever vs. time during slide-hold-slide tests made for different hold times at the same loading velocity. The vertical dashed line indicates the time when the cantilever starts to slide. The tip appex does not move until the cantilever's driving force exceeds the static friction threshold at the surface which is higher for longer hold times.

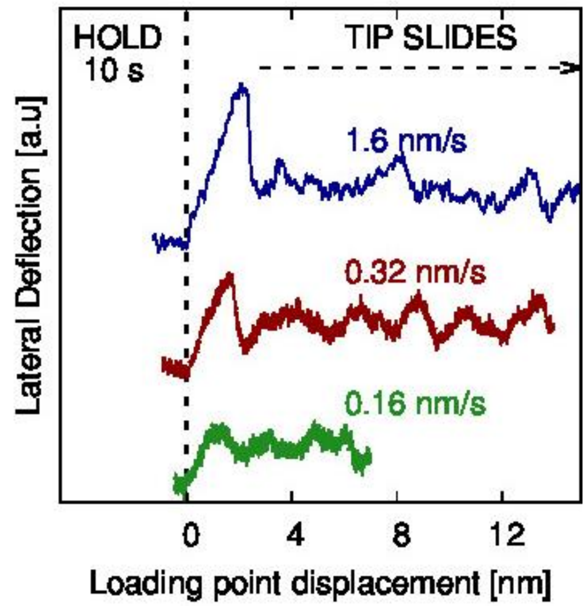

Figura 3. Lateral deflection of the cantilever vs. displacement of the loading point during slide-hold-slide tests made for different loading velocities at the same hold time. The vertical dashed line indicates the time when the cantilever starts to slide. The tip appex does not move until the cantilever's driving force exceeds the static friction threshold at the surface which is higher for higer loading velocities.

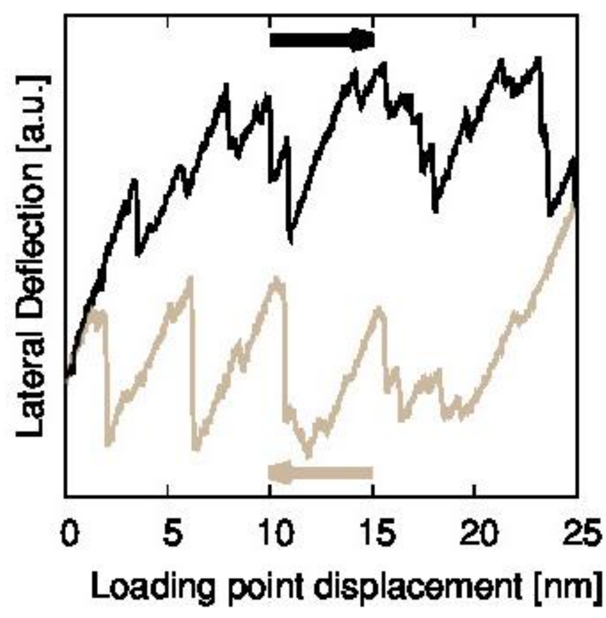

Figura 4. Lateral deflection of the cantilever vs. displacement of the loading point showing a typical stick-slip friction loop. Arrows indicate direction of motion.