'Heftier' atoms reduce friction at the nanoscale

November 1 2007

A research team led by a University of Pennsylvania mechanical engineer has discovered that friction between two sliding bodies can be reduced at the molecular, or nanoscale, level by changing the mass of the atoms at the surface. “Heavier” atoms vibrate at a lower frequency, reducing energy lost during sliding.

The study appears in the November issue of the journal *Science*.

Penn researchers, along with colleagues at the University of Houston and the University of Wisconsin now at IBM’s Zurich Research Laboratory and the Argonne National Laboratory, used atomic force microscopy like an old-fashioned record needle, sliding it along single-crystal diamond and silicon surfaces to measure the force of friction.

Before doing so, researchers coated each crystal surface with one of two adsorbates designed to best exhibit variations in the mass of the atoms at the surface without changing the chemistry. The first adsorbate was a single layer of hydrogen atoms. The second was its chemically similar but heavier cousin, deuterium, a hydrogen atom with a neutron stuffed inside its nucleus.

“Our study found that the larger mass of the terminating atoms at the surface, in this case deuterium, led to less energy lost to heat in the system,” Robert Carpick, associate professor of mechanical engineering and applied mechanics at Penn, said. “The larger atomic mass of deuterium results in a lower natural vibration frequency of the atoms.

These atoms collide less frequently with the tip sliding over it, and thus energy is more slowly dissipated away from the contact."

The single layer of atoms at the surface of each crystal acts as an energy transfer medium, absorbing kinetic energy from the tip of the atomic force microscope. The tips were less than 50nm in radius at their ends. How much energy is absorbed is dependent, researchers found, on the adsorbates' natural atomic vibration frequencies. The heavier an atom, the lower its vibrational frequency. The lighter an atom, the faster the vibrations and thus the faster the dissipation of energy from the contact in the sample. Keeping the atoms chemically similar avoided any changes arising from chemical bonding.

The Penn findings provide a better understanding of the nature of friction, which lacks a comprehensive model at the fundamental level.

"We know how some properties -- adhesion, roughness and material stiffness for example -- contribute to friction over several length scales, but this work reveals how truly atomic-scale phenomena can and do play a meaningful role," Matthew Brukman, a contributor to the research, said.

Industry has long been concerned with ways to reduce friction between objects, both to maintain the energy of the system as well as to reduce heat-generation and wear, which can weaken machinery and materials to the breaking point. The authors note that improved friction models can be used for the opposite effect; makers of some mechanical components such as automobile clutches may be interested in techniques to increase friction without changing the wear or adhesion of materials.

Even in the absence of rough edges or wear between sliding bodies, friction between the atoms at the surface causes vibrations which dissipate energy, but the exact mechanisms of this process remain unresolved. Scientists continue to explore the details of friction, and other open questions include the effects of environmental variables such as temperature and atmosphere.

Source: University of Pennsylvania