University of Pennsylvania engineers reveal what makes diamonds slippery at the nanoscale

June 23 2008

They call diamonds "ice," and not just because they sparkle. Engineers and physicists have long studied diamond because even though the material is as hard as an ice ball to the head, diamond slips and slides with remarkably low friction, making it an ideal material or coating for seals, high performance tools and high-tech moving parts.

Robert Carpick, associate professor in the Department of Mechanical Engineering and Applied Mechanics at the University of Pennsylvania, and his group led a collaboration with researchers from Argonne National Laboratories, the University of Wisconsin-Madison and the University of Florida to determine what makes diamond films such slippery customers, settling a debate on the scientific origin of its properties and providing new knowledge that will help create the next generation of super low friction materials.

The Penn experiments, the first study of diamond friction convincingly supported by spectroscopy, looked at two of the main hypotheses posited for years as to why diamonds demonstrate such low friction and wear properties. Using a highly specialized technique know as photoelectron emission microscopy, or PEEM, the study reveals that this slippery behavior comes from passivation of atomic bonds at the diamond surface that were broken during sliding and not from the diamond turning into its more stable form, graphite. The bonds are passivated by dissociative adsorption of water molecules from the surrounding environment. The researchers also found that friction increases dramatically if there is not enough water vapor in the environment.

Some previous explanations for the source of diamond's super low friction and wear assumed that the friction between sliding diamond surfaces imparted energy to the material, converting diamond into graphite, itself a lubricating material. However, until this study no detailed spectroscopic tests had ever been performed to determine the legitimacy of this hypothesis. The PEEM instrument, part of the Advanced Light Source at Lawrence Berkeley National Laboratory, allowed the group to image and identify the chemical changes on the diamond surface that occurred during the sliding experiment.

The team tested a thin film form of diamond known as ultrananocrystalline diamond and found super low friction (a friction coefficient ~0.01, which is more slippery than typical ice) and low wear, even in extremely dry conditions, (relative humidity ~1.0%). Using a microtribometer, a precise friction tester, and X—ray photoelectron emission microscopy, a spatially resolved X-ray spectroscopy technique, they examined wear tracks produced by sliding ultrananocrystalline diamond surfaces together at different relative humidities and loads. They found no detectable formation of graphite and just a small amount of carbon re-bonded from diamond to amorphous carbon. However, oxygen was present on the worn part of the surface, indicating that bonds broken during sliding were eventually passivated by the water molecules in the environment.

Already used in industry as a mechanical seal coating to reduce wear and improve performance and also as a super-hard coating for high-performance cutting tools, this work could help lead to increased use of diamond films in machines and devices to increase service life, prevent wear of parts and save energy wasted by friction.

Source: University of Pennsylvania