Tribology Focus Topic
Room: Tesuque - Session TR+NS+SS-WeA

Mechanical & Chemical Effects on Friction and Wear
Moderator: S.S. Perry, University of Florida

2:00pm **TR+NS+SS-WeA1 Quantitative Assessment of Sample Stiffness and Sliding Friction from Force Curves in Atomic Force Microscopy**, *J.R. Pratt, G.A. Shaw,* NIST, *L. Kumanchik*, University of Florida, ***N.A. Burnham***, Worcester Polytechnic Institute

It has long been recognized that the angular deflection of an atomic force microscope (AFM) cantilever under "normal" loading conditions can be profoundly influenced by the friction between the tip and the surface. It is shown here that a remarkably quantifiable hysteresis occurs in the slope of loading curves whenever the normal flexural stiffness of the AFM cantilever is *greater* than that of the sample. This situation arises naturally in cantilever-on-cantilever calibration, but also when trying to measure the stiffness of nanomechanical devices or test structures, or when probing any type of surface or structure that is much more compliant along the surface normal than in transverse directions. Expressions and techniques for evaluating the coefficient of sliding friction between the cantilever tip and sample from normal force curves, as well as relations for determining the stiffness of a mechanically compliant specimen are presented. The model is experimentally supported by the results of cantilever-on-cantilever spring constant calibrations. The cantilever spring constants determined here agree with the values determined using the NIST electrostatic force balance within the limits of the largest uncertainty component, which had a relative value of less than 2.5%. This points the way for quantitative testing of micromechanical and nanomechanical components, more accurate calibration of AFM force, and provides nanotribologists access to information about contact friction from normal force curves [1].

1. J. Appl. Physics **107**, 044305 (2010), doi:10.1063/1.3284957

2:20pm **TR+NS+SS-WeA2 Nanotribological Properties of Polyzwitterionic Brushes**, ***Z. Zhang***, *A.J. Morse, S.P. Armes*, University of Sheffield, UK, *A.L. Lewis*, Biocompatibles UK Ltd., UK, *G.J. Leggett*, University of Sheffield, UK

2:40pm **TR+NS+SS-WeA3 Atomic-scale Processes in Friction and Wear: From Diamond to Graphene**, ***R.W. Carpick***, University of Pennsylvania **INVITED**

Nanoscale friction and wear are primary limitations for small-scale devices such as atomic force microscopy (AFM) probes and micro- or nano-electronic mechanical systems with contacting surfaces, and is also relevant to understanding friction and wear in larger-scale contacts. We first present studies that quantify the nanoscale volume loss in sliding wear using AFM and periodic *ex-situ* transmission electron microscopy (TEM) imaging. Novel carbon-based AFM tip materials, including ultrananocrystalline diamond and diamondlike carbon, exhibit superior wear resistance compared to conventional materials (silicon and silicon nitride)[1-3]. We then present results from wear tests performed inside of the TEM using modified *in-situ* indentation techniques. This permits real-time visualization of the contact geometry and shape evolution of a single asperity with sliding over a countersurface. This allows us to measure wear with a higher degree of precision than previously possible. Insights comparing the wear resistance of carbon-based and Si-based materials, particularly in the context of atom-by-atom wear processes, will be discussed[4]. Finally, we will discuss how nanoscale friction in graphene and other atomically-thin sheets is governed by the high flexibility intrinsic to the atomic scale[5].

1. *Prevention of nanoscale wear in atomic force microscopy through the use of monolithic ultrananocrystalline diamond probes.* J. Liu, D.S. Grierson, J. Notbohm, S. Li, S.D. O'Connor, K.T. Turner, R.W. Carpick, P. Jaroenapibal, A.V. Sumant, J.A. Carlisle, N. Neelakantan & N. Moldovan, **Small**, in press (2010).

2. *Ultra-low nanoscale wear through atom-by-atom attrition in silicon-containing diamond-like-carbon.* H. Bhaskaran, B. Gotsmann, A. Sebastian, U. Drechsler, M. Lantz, M. Despont, P. Jaroenapibal, R.W. Carpick, Y. Chen & K. Sridharan, **Nature Nanotechnology** 5, 181-185 (2010).

3. *Wear resistant diamond nanoprobe tips with integrated silicon heater for tip-based nanomanufacturing.* P.C. Fletcher, J.R. Felts, Z. Dai, T.D. Jacobs, H. Zeng, W. Lee, P.E. Sheehan, J.A. Carlisle, R.W. Carpick & W.P. King, **ACS Nano**, accepted (2010).

4. *On the application of transition state theory to atomic-scale wear.* T.D. Jacobs, B. Gotsmann, M.A. Lantz & R.W. Carpick, **Tribol. Lett.**, accepted (2010).

5. *Frictional characteristics of atomically-thin sheets.* C. Lee, Q. Li, W. Kalb, X.-Z. Liu, H. Berger, R.W. Carpick & J. Hone, **Science** 328, 76-80 (2010).

4:00pm **TR+NS+SS-WeA7 Lubricin Reduces Microscale Cartilage Wear**, ***J.M. Coles***, *D.P. Chang*, Duke University, *L. Zhang, G.D. Jay*, Brown University / Rhode Island Hospital, *F. Guilak, S. Zauscher*, Duke University

Articular cartilage is the load bearing surface of mammalian joints. Relatively little wear occurs in cartilage and the tissue is able to sustain millions of loading cycles despite limited regenerative capacity. Though many studies of cartilage friction and lubrication have been performed, often with a stated goal of understanding cartilage wear prevention, very few have measured wear directly and none have directly assessed the effects of synovial fluid constituents in mediating wear. Here we show that the synovial fluid glycoprotein lubricin reduces microscale cartilage wear in vitro. We used colloidal probe microscopy to induce wear and use the change in the average height of the surface as a measure of worn volume. The height change in locations worn in the presence of lubricin was significantly less than in those worn in the control solution. These data indicate that lubricin is important for cartilage preservation physiologically and may have implications for treating or preventing joint disease.

4:20pm **TR+NS+SS-WeA8 Friction of Metallic Nanoparticles: The Influence of Particle Morphology, Orientation and Air Exposure**, *D. Dietzel, T. Moenninghoff, C. Herding, M. Feldmann, H. Fuchs,* Westfaelische Wilhelms-Universitaet Muenster, Germany, *C. Ritter*, ***U.D. Schwarz***, Yale University, *A. Schirmeisen*, Westfaelische Wilhelms-Universitaet Muenster, Germany

The contact area dependence of the interfacial friction experienced during the translation of the antimony is studied under different conditions using the tip of an atomic force microscope as a manipulation tool [1]. In vacuum a dual behavior in the friction-area curves is found had been found earlier, characterized by the observation that some particles exhibit friction below the detection limit while other similarly sized particles showed constant shear stress values [2]. New investigations with improved sensitivity confirm the reproducibility of this effect and that neither the particle's morphology nor their relative orientation towards the substrate lattice change this behavior. In contrast, we find that a temporary exposure to ambient air can lead to a drastic increase in the particle's friction.

[1] A. Schirmeisen and U. D. Schwarz, ChemPhysChem 10 (2009) 2358

[2] D. Dietzel et al., Physical Review Letters 101 (2008) 125505

4:40pm **TR+NS+SS-WeA9 Modeling Materials in Contact using Molecular Simulation**, ***J.D. Schall***, *R.V. Petrach*, Oakland University **INVITED**

Molecular dynamics (MD) simulation has become an extremely powerful tool for materials science research due to the wealth of atomic level information it provides. In this talk an overview of the MD simulation method will be given. Then a number of applications where MD simulations have been applied to study materials in contact will be discussed. Topics will include the tribology of amorphous carbon films in the presence of hydrogen, and recent work involving the indentation of free-standing graphene sheets. In simulation of the tribology of amorphous carbon, chemical reactions between opposing films were monitored and used to elucidate the mechanisms for enhanced friction and wear properties and to discover the mechanisms of transfer layer formation. These simulations illustrate the need for surface passivation of amorphous carbon films in applications where low friction is desired. We have also investigated the role of silicon on the properties of these films using a parametrization of Brenner's second generation reactive empirical bond order potential for Si-C-H interactions. Recent results of the simulation of indentation of free-standing graphene films will be shared.

5:20pm **TR+NS+SS-WeA11 Modeling Tribochemistry of DLC vs DLC in the Presence of Water**, ***J.A. Harrison***, *P.T. Mikulski, M.T. Knippenberg*, United States Naval Academy

Because the structure and properties of diamond-like carbon (DLC) can vary depending upon deposition conditions, the tribological response of DLC (and diamond) is very sensitive to environmental conditions. For instance, the presence of water vapor has been shown to negatively impact the friction performance of hydrogenated DLCs but to improve the performance of nanocrystalline and ultrananocrystaline DLCs. Tribochemical reactions of the water with the DLC are thought to be at the heart of this long-standing puzzle.

With that in mind, we have been working to develop a potential energy function that is capable of modeling DLC in the presence of water. To be realistic, such a potential energy function should be able to model tribochemical reactions that may occur as a result of the sliding. In addition, because H, C, and O have very different electronegativities, the potential energy function must be capable of modeling charges and fluctuating charges that arise from electronegativity differences in a realistic way. This talk will outline our efforts at potential development and present some preliminary results of DLC friction in the presence of water.

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5:40pm **TR+NS+SS-WeA12 Effects of Impact and Sliding Forces on Failure Behavior of a DLC Coating**, ***J.F. Su***, *L. Wang*, *X. Nie*, University of Windsor, Canada

The wear and tribological properties of diamond-like carbon (DLC) coatings have been investigated and well documented under various laboratorial and industrial conditions. However, investigations into failure behavior of the coatings when subjected to cyclic impact-sliding loads are scarce. In this study, an inclined ball-on-plate impact-sliding tests were used to evaluate the fatigue cracking and peeling failure behavior of a DLC (a-C:H) coating and a TiN coating as comparison. By adjusting the impact velocity of a steel impacting ball that is connected to and driven by air cylinder, various dynamic impact loads can be obtained. The impact load vs. time curves were recorded and showed three stages, i.e., impact loading stage, vibration stage and quasi-static sliding stage for each impact-sliding cycle. Four loading combinations of impact/static forces (50N/100N, 100N/100N, 50N/200N and 100N/200N) were used in the tests. The test results showed that the DLC coating performed better than the TiN coating under the impact forces but worse under the sliding stages where the quasi-static force was applied by the air cylinder.

Authors Index

Bold page numbers indicate the presenter