Tribology Focus Topic
Room: 19 - Session TR+BI-TuM

Self Healing Coatings, Bio-Inspired Design, and Frictional Properties of Biological Materials

Moderator: D. Irving, North Carolina State University, M.O. Robbins, Johns Hopkins University

8:20am **TR+BI-TuM2 Friction at Hydrogel Contact Lens Surfaces**, ***S.S. Perry***, *S. Huo, A. Rudy*, University of Florida **INVITED**

The surfaces of six types of silicone hydrogel (SH) contact lenses (PureVision®, O_2 OPTIX®, ACUVUE® Oasys ®, ACUVUE® TruEye®, Biofinity®, DAILIES TOTAL1®) and the pHEMA-based ACUVUE® 2 have been analyzed using atomic force microscopy (AFM) in aqueous environment. The elastic modulus, frictional, and adhesive properties of each lens were evaluated using calibrated instrumentations, providing a basis for comparing the distinctive surface properties of these lenses. Cantilevers modified with 5-μm (diameter) silica colloidal probes were employed throughout the experiments. Elastic modulus was measured by indenting the probe into the surface of the hydrogel in a controlled manner (i.e. approach speed and maximum applied force), such that the maximum indentation depth was restricted to sub-micron levels. A modulus value was obtained by fitting the characteristic force versus indentation behavior to a mathematical model. The frictional force was measured for the sliding contact of the probe and the surface at the length scale of 500 nm and with applied loads up 20 nN. The friction coefficient was realized by evaluating the linear dependence of friction force on applied normal load. The lenses examined exhibited an order of magnitude difference—from the softest to the stiffest sample—in modulus value, generally reflective of the distinct surface treatments they received during manufacturing. For example, the pHEMA-based ACUVUE® 2 was shown to have a modulus between 100 and 130 kPa, whereas PureVision®'s was an order of magnitude higher in value. The frictional properties of the lenses followed a similar trend in that the lenses with surface treatment, such as PureVision® and O_2OPTIX®, generally exhibited coefficients of friction five times greater than that of a non-treated lens such as ACUVUE® OASYS®. The elastic modulus and frictional properties of different lenses evaluated on a nanoscopic level by AFM depict a strong correlation between the surface treatments and the apparent mechanical behaviors of the lenses.

9:00am **TR+BI-TuM4 Linking Cartilage Structure, Lubrication, and Osteoarthritis**, ***D.L. Burris***, University of Delaware

Cartilage is known for exceptionally low friction coefficients during sliding, but its wear resistance is arguably more remarkable. Conventional wisdom suggests that cartilage wears gradually with use and that osteoarthritis is the inevitable consequence. This notion is refuted by the scientific literature. Dissections of mature, healthy, and active joints consistently reveal smooth, glossy, damage-free articulating surfaces that can only occur if tissue recovery matches wear. Cartilage recovery is extremely slow due to a lack of vasculature and numerous lubrication mechanisms have been proposed to explain extremely low in-vivo wear rates. Osteoarthritis (OA) is characterized by progressive wear and caused by a system destabilizing input (*e.g.* biochemistry, acute injury, altered loading, and joint instability). In certain joint-destabilized animal models, for example, a localized defect (~50 μm wide) is visible in as little as a week, and bone-on-bone contact occurs on the order of 6 months. Recent studies suggest that interstitial lubrication, a mechanism that reduces frictional and normal stresses by nearly 100X, is the dominant protective mechanism of cartilage. Localized surface damage can disrupt the very specific structural features responsible for the unique interstitial fluid pressurization mechanism. We hypothesize that localized surface damage can initiate OA-like degradation if it is sufficiently disruptive to the interstitial lubrication mechanism. In this paper, we present friction and wear measurements designed to explore this novel mechanical hypothesis of OA initiation and progression.

9:20am **TR+BI-TuM5 Self Healing Materials: A New Approach to Make Materials Perform More Reliably under Harsh Conditions**, ***S. van der Zwaag***, *M. Valefi, S. Garcia, M.R. de Rooij*, Delft University of Technology and University of Twente, the Netherlands **INVITED**

Currently all engineering materials are designed on the basis of the 'amage prevention' paradigm i.e. the microstructure is designed such that damage forms as late as possible and grows slowly, but no mechanisms are built in which can reduced damage once formed. Materials in nature on the other hand seem optimised on the basis of 'damage management' paradigm, i.e. the occurrence of damage is taken as unavodidable and the material has the in-built ability to repair the damage during less demanding stages of the loading cycle. In this presentation we will show various approaches to self healing behaviour in a wide range of material classes and also show how self healing concepts can be used to mitigate tribological damage in both ceramics and polymeric materials. The experimental results are supported by a simple mechanical model.

10:40am **TR+BI-TuM9 Surface Analytical and Tribological Characterization of Diamonlike Boundary Films Extracted from Base Mineral and Synthetic Oils**, ***A. Erdemir***, *O.L. Eryilmaz*, Argonne National Laboratory

In this study, we explored the possibility of deriving carbon-based bounary films directly from base lubricating oils during tribological tests. For this purpose, we first designed and deposited a series of catalytically active nanocomposite coatings on some steel substrates and by adjusting the ratios of softer phases made out of known catalysts and harder nitride phases (that are also catalytically active), we were able to extract carbon-based boundary films from the base oil molecules and deposit them as protective boundary films on rubbing surfaces. Using UV Raman and variety of other surface and structure analytical techniques,we were able to confirm that these boundary films were indeed similar to those diamonlike carbon films that are typically synthesized using CVD and PVD methods. Some of the main characteristics of resultant DLC boundary films were: very low friction coefficients (less than 0.05) even under extreme sliding conditions and very high resistance to wear and scuffing. In this paper, we will provide insight into the structural and chemical nature of these tribofilms and explain fundamental mechanisms for their impressive tribological properties under severe test conditions.

11:00am **TR+BI-TuM10 Data-driven Model for Estimation of Friction Coefficient via Informatics Methods**, *E.W. Bucholz*, University of Florida, *C.S. Kong*, Iowa State University, *K.R. Marchman, F.-Y. Lin, W.G. Sawyer, S.R. Phillpot*, University of Florida, *K. Rajan*, Iowa State University, ***S.B. Sinnott***, University of Florida

The rapid development of new mechanical assemblies capable of operating in extreme conditions requires the rapid determination/estimation of friction. Often, during the design phase, materials friction coefficients are unknown. Here, data mining and materials informatics methods are used to generate a predictive model that enables efficient high-throughput screening of ceramic materials, some of which are candidate high-temperature solid-state lubricants. Through the combination of principal component analysis and recursive partitioning using a small dataset comprised of intrinsic material properties, we develop a decision tree based model comprised of if-then rules, which estimates the friction coefficients of a wide range of materials derived from the interrelationships between the intrinsic material properties. This predictive model lays the foundation for new studies in predictive modeling and tailoring materials with specific tribological characteristics. It is applied to predict the tribological performance of a range of different materials.

This work is supported by the Office of Naval Research.

11:20am **TR+BI-TuM11 Structure, Lateral Flow, and Self-Healing of a Bound-and-Mobile Lubricant Film**, ***S.H. Kim***, Pennsylvania State University **INVITED**

There have been a significant amount of efforts to develop boundary lubrication films that have the bound and mobile natures at the same time. As an effort to develop a more efficient boundary film lubrication method, a new bound-and-mobile lubricant molecule was synthesized and its lubrication and self-healing capability was studied. Low-molecular-weight silicone molecules with cationic side groups can form bound-and-mobile boundary lubrication film on silicon oxide surface. Both nano- and macro-scale tribological tests revealed superior lubrication performance of the silicone polymer with cationic side chains (called cationic lubricant polymer, CPL) over the neutral silicone oil. The multilayer CPL films exhibited characteristic topographic features due to ionic interactions within the polymeric film. In the macro-scale, the effects of ionic content and environmental condition on self-healing will be discussed to demonstrate the wear resistance and self-healing capability. In the nanoscale, the results of disjoining pressure and viscosity measurements help understand the lateral spreading of the mobile layer and identify the mobile species. The CPL-coated surfaces are hydrophobic which prevents the detrimental effects of humidity on wear of silicon. In addition, the hygroscopic nature of CPL allows humidity to be absorbed into the film, which enhances the self-healing capabilities. By texturing the silicon surface with nanowells, self-healing can be enhanced when the nanowells are filled with CPL. The nanowells serve as CPL reservoirs that are readily available for self-healing within the wear track for faster cycle intervals. However, the nanowells

deteriorate the self-healing from surrounding the contact region due to the refilling of the empty nanowells.

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