Tribology Focus Topic
Room: 230B - Session TR+TF-ThM

Nanolubricants and Coatings
Moderator: Tevis Jacobs, University of Pittsburgh

8:00am **TR+TF-ThM1 Mechanical Mixing and Wear Formation in Metallic Tribocouples**, ***Martin Dienwiebel***, *P. Stoyanov, T. Feser,* Karlsruhe Institut for Technology (KIT), Germany, *R. Merz,* Insitut für Oberflächen und Schichtanalytik GmbH, Germany, *P. Romero,* Fraunhofer Institute for Mechanics of Materials IWM, Germany, *F.C. Wählisch,* INM - Leibniz-Institute for New Materials, Germany, *P. Stemmer,* University of Duisburg-Essen, Germany, *M. Moseler,* Fraunhofer Institute for Mechanics of Materials IWM, Germany, *R. Bennewitz,* INM - Leibniz-Institute for New Materials, Germany, *A. Fischer*, University of Duisburg-Essen, Germany **INVITED**

During sliding of metallic surfaces in dry or lubricated conditions the near surfaces undergo significant changes in terms of topography, composition and microstructure [1] and a so-called *"third body"* or *"tribomaterial"* [2] develops. The third-body formation strongly influences the frictional and wear behavior of the system.

In this talk we present several experiments on pure metals and alloys that were performed using a novel experimental platform for the on-line correlation of friction, wear and topography under lubricated sliding [3]. Fast topography data is measured in real time by digital holography microscopy (DHM), wear is measured by the Radionuclide wear technique (RNT) and the nanoscale topography is obtained *in-situ* by liquid atomic force microscopy (AFM). The tribological systems that we recently studied include a-brass (CuZn) sliding against steel [4], tungsten and tungsten carbide [5], [6]. The experimental findings were compared to MD simulations. In order to characterize the mechanical behavior, nanoindentation and micropillar compression tests were performed that show that the third body material is softening during the initial running-in [7].

References

[1] M. Scherge, D. Shakhvorostov, K. Pöhlmann, Wear, 255 (2003) 395-400.

[2] M. Godet, Wear, 100 (1984) 437–452.

[3] S. Korres, M. Dienwiebel, Rev. Sci. Instr., 81 (2010) 063904.

[4] T. Feser, P. Stoyanov., M. Dienwiebel, Wear, 303 (2012) 465-472

[5] P. Stoyanov et al. , Tribol. Lett., 50 (2013) 67-80.

[6] P. Stoyanov et al., ACS Appl. Mat. & Int.s, 5 (2013) 6123-6135.

[7] P. Stoyanov et al., ACS Nano 9 (2015) 1478

8:40am **TR+TF-ThM3 Influence of MoDTC Degradation on Tribological Performances of Steel-Steel Contacts under Boundary Lubrication Conditions**, ***Clotilde Minfray***, *M. De Feo, M.I. De Barros Bouchet,* Ecole Centrale de Lyon - LTDS, France, *B. Thiebaut,* Solaize Research Center, France, *T. Le Mogne, B. Vacher, J.M. Martin*, Ecole Centrale de Lyon - LTDS, France

Nowadays, MoDTC is one of the best-known friction modifier additives used in engine oils for its friction reduction properties. A vast number of papers tackle the subject and converge on the fact that the generation of MoS_2 flake in the contact (in tribofilm) is at the origin of the friction reduction. But it is also known that this positive friction reduction effect is not so durable in time. Therefore, the investigation of MoDTC chemical degradation mechanism and its impact on the tribological properties in steel/steel contacts is of great interest.

It is proposed here to age a lubricant made of mineral base oil blended with 1%w of MoDTC with a thermo-oxidative procedure (open air - 160°C) for different durations. The aged lubricants are then tested under boundary lubrication conditions, with ball-on-flat reciprocating tests running at 100°C. Balls and flats are both in AISI52100 steel.

Concerning the results, clear differences are found in terms of friction behavior as a function of ageing time. A relation between ageing and induction time needed to reach the "low" friction regime is also established. Tribofilms generated on flats were then analyzed by means of XPS surface analysis and FIB-TEM observations for a precise chemical and morphological characterization of each flat sample. The possible presence of two types of molybdenum oxi-sulfide compounds, more or less oxidized, is suggested by XPS results and discussed regarding the friction behavior. Moreover, the TEM observations carried out suggest tribofilms differences in terms of morphology, size and organization. Finally, the effect of MoDTC ageing on friction behavior is discussed considering the composition of tribofilms but also taking into account MoDTC depletion in the bulk of the lubricant, thanks to High Performance Liquid Chromatography (HPLC) experiments.

9:20am **TR+TF-ThM5 General Model for Tribology of Metallic Contacts**, ***Michael Chandross***, Sandia National Laboratories, *S. Cheng,* Virginia Tech, *N. Argivay*, Sandia National Laboratories **INVITED**

The tribology community presently relies on phenomenological models to describe the various seemingly disjointed steady-state regimes of metal wear. Pure metals such as gold -- frequently used in electrical contacts -- exhibit high friction and wear. In contrast, nanocrystalline metals, such as hard gold, often show much lower friction and correspondingly low wear. The engineering community has generally used a phenomenological connection between hardness and friction/wear to explain this macroscale response, and thus to guide designs. We present a suite of recent simulations and experiments that demonstrate a general framework for connecting materials properties (i.e. microstructural evolution) to tribological response. We present evidence that the competition between grain refinement (from cold working), grain coarsening (from stress-induced grain growth), and wear (delamination and plowing) can be used to describe transient and steady state tribological behaivor of metals, alloys and composites. We will present the results of large-scale molecular dynamics simulations and targeted experiments that explore the seemingly disjointed steady-state wear regimes of metals and alloys, with a goal of elucidating the structure-property relationships, allowing for the engineering of tribological mateirals and contacts based on the kinetics of grain boundary motion.

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11:20am **TR+TF-ThM11 Superlubric Sliding of Gold Nanoparticles on Graphite under Ambient Conditions**, *E. Cihan,* ***Mehmet Z. Baykara***, Bilkent University, Turkey

Forming a complete understanding of the physical mechanisms that govern friction on the nanometer and atomic scales is an ongoing endeavor for scientists from various disciplines. While atomic force microscopy (AFM) has proven to be invaluable for the detailed study of nano-scale frictional properties associated with various surfaces, issues related to the precise characterization of the contact formed by the probe tip and the sample surface remain largely unsolved.

In recent years, an alternative approach to nanotribology experiments has involved the lateral manipulation of well-characterized nanoparticles on sample surfaces via AFM and the measurement of associated frictional forces [1]. In line with this idea, we present ambient-condition nano-manipulation experiments involving gold nanoparticles (AuNP) thermally deposited on highly oriented pyrolytic graphite (HOPG), a sample system which has been recently characterized in detail [2]. It is observed that AuNPs experience remarkably low frictional forces during sliding. A detailed study of friction with respect to contact area firmly confirms the occurrence of *superlubric* sliding under ambient conditions for this sample system. The potential reasons behind the observed phenomenon are discussed with support from theoretical considerations.

[1]: D. Dietzel, U.D. Schwarz, A. Schirmeisen, Friction **2**, 114-139 (2014)

[2]: E. Cihan, A. Özoğul, M.Z. Baykara, Applied Surface Science, (2015), DOI: 10.1016/j.apsusc.2015.04.099

11:40am **TR+TF-ThM12 Monitoring the Gas-Phase Products of a Shear-Induced Reactions in Ultra-high Vacuum**, ***Heather Adams***, University of Wisconsin-Milwaukee, *M.T. Garvey,* Illinois Applied Research Institute, *O. Furlong,* Universidad Nacional de San Luis, Argentina, *W.T. Tysoe*, University of Wisconsin-Milwaukee

Although tribochemical reactions are common in manufacturing, analysis of the mechanism and products is severely limited by the difficulty of probing a solid-solid interface that changes on small time scales. A method to analyze the gas-phase products of a tribochemical reaction in ultra-high vacuum has been developed to allow insight to be obtained into the decomposition pathways of short-chain alkylthiols on copper foils. A UHV-tribometer is used to probe the alkylthiol-covered copper foil by using a mass spectrometer to measure the products evolved from the surface.

Alkylthiols have been chosen due to their thermal stability on a copper surface[1], and their ability to form a tribofilm. Previous studies have found that sulfur moves into the sub-surface layer with rubbing, and the carbon is removed from the surface.[2]

The shear-induced decomposition of methyl thiolate produces gas-phase methane and measuring the amount of methane produced during each sliding cycle allows the shear-induced reaction rate to be measured. The results are analyzed to give insight into how sheer stress lowers the energy barrier for the decomposition reaction. [3]

1. Furlong, O. J. *et al.* The surface chemistry of dimethyl disulfide on copper. *Langmuir* **26,** 16375–16380 (2010).

2. Furlong, O., Miller, B., Kotvis, P., Adams, H. & Tysoe, W. T. Shear and thermal effects in boundary film formation during sliding. *RSC Adv.* **4,** 24059 (2014).

3. Adams, H. L. *et al.* Shear-Induced Mechanochemistry: Pushing Molecules Around. *J. Phys. Chem. C* **119,** 7115–7123 (2015).

Authors Index

Bold page numbers indicate the presenter