Friday Morning, October 25, 2019

Advanced Surface Engineering Division
Room A215 - Session SE+AS+SS-FrM

Tribology: From Nano to Macro-scale

Moderators: Robert Franz, Montanuniversität Leoben, Andrey Voevodin, University of North Texas

8:20am **SE+AS+SS-FrM-1 The Scaling of Tribological Effects from Nano- to Macro-scale*, Peter Lee,*** Southwest Research Institute **INVITED**

The last few decades has seen the advancement of technologies such as atomic force microscopes (AFM), scanning force microscopes (SFM) and friction force microscopes (FFM) to measure friction, wear and adhesions at the nano- and micro-scale, leading to the study of nano- and micro-tribology. The study of two surfaces at the nano- and micro-meter scale has led to the advancement of small scale engineering devices such as nano- and micro-electromechanical systems (NEMS and MEMES). However, it has also led to the study of materials used in macro-engineering in an attempt to understand the fundamentals of lubrication, friction and wear at the asperity scale in macro-systems.

Macro-tribology involves large apparent areas of contact where only a fraction of the asperity tips are in contact, whereas nano-tribology usually involves studying a single asperity contact where the actual contact is the same as the apparent contact. Consequently, roughness and actual contact shape plays a more significant role in the tribological behavior, which in turn means significant effects on forces such as friction, adhesion and surface tension. Tribology at the macro-scale is governed by complex phenomena such as ploughing, abrasive, and adhesive wear. Friction at the nano-scale is often studied purely in the wearless (interfacial) regime, where adhesion is substantial but wear is minimal.

This presentation will explore current research at the nano-scale and discuss how this has the potential to help in understanding and modeling at the macro-scale.

9:00am **SE+AS+SS-FrM-3 Nanotribology of Graphene in Organic Solvents*, Prathima Nalam,*** *B Sattari Baboukani,* University at Buffalo, State University of New York*; Z Ye,* Miami University

Two-dimensional (2D) materials such as graphene, *etc.* are emerging as friction-reducing additives for transmission fluids and lubricating oils to enhance the service life of sliding metallic components. Here in this work, we investigate the dissipative mechanism for a supported (on silica substrate), monolayer of graphene when immersed in organic solvents such as *n*-hexadecane and cyclohexane. Nanoscale friction measurements on graphene conducted using atomic force microscope showed a non-monotonic variation *i.e.* a decrease and then an increase in friction forces as a function of immersion time in organic solvents. This behavior was attributed to the re-arrangement of organic molecules at the 2D confinement formed between the graphene and the underlying substrate. The oscillatory forces measured at the interface showed an increased packing order of the solvent molecules under 2D confinement and with equilibration time lead to a higher dissipative interface. The diffusion of organic molecules to the 2D confinement also results in a partially-suspended graphene layer and the interfacial friction is discussed by understanding the quality (local pinning states of individual atoms) of the contact made by the AFM probe while sliding on graphene.

9:20am **SE+AS+SS-FrM-4 Measuring Atomicscale Surface Friction of a Molecular Vehicle on Au(111)***, K Latt,* ***Sanjoy Sarkar****, K Kottur, M Raeis,* Ohio University*; A Ngo,* Argonne National Laboratory*; R Tumbleson, Y Zhang, E Masson, S Hla,* Ohio University

Designing molecules with technomimetic properties has been actively pursued in the past decade. Among these, molecules specially designed for translational motion, dubbed as nanocars or molecular vehicles, are particularly appealing as they could ultimately be used to transport a molecular cargo or some specific chemical information from a start to an end point on a surface and on demand. Here, we have designed and assembled an electric nanovehicle using four molecular wheels and a molecular chassis as separate modules. An 'H' shape chasis is formed by two benzimidazolium groups linking the front and the rear axles to a terphenyl drive shaft. Final assembly of the nanovehicle is realized by attaching four pumpkin shaped cucurbituril molecular wheels. The chassis of the nanovehicle includes positive charges, which are used for the controlled lateral movement of the vehicle by scanning tunneling microscope tip induced electric field manipulation. The threshold voltage required to drive the nanovehicle is determined from the Vaussian-fit of the data. Moreover, we have determined lateral force to move the nanovehicle on a Au(111) surface at 5K and it is found to be in superlubricity regime.

9:40am **SE+AS+SS-FrM-5 The Use of the Nanocomposite Concept in Hard Coatings for Improving the Frictional Performance*, Albano Cavaleiro,*** University of Coimbra, Portugal **INVITED**

Nanocomposite thin films based on a structural arrangement consisting of grains of a transition metal nitride enrobed in a thin layer of silicon nitride, have been developed in last decades with the final aim of maximizing the mechanical strength. This specific arrangement was proved to be efficient regarding the oxidation resistance and the structural stability at high temperatures as well as the wear resistance, reason why these coatings are commercially available in the market. However, their performance in applications requiring low friction, against specific materials, is very inefficient. On the other hand, in last years the addition of elements, able to provide low friction, such as Ag or V, to traditional hard coatings (TiN, TiAlN, TiCrN,…) has been deeply studied. Results were very successful from the lubrication point of view but the wear resistance was clearly reduced, due to either a decrease of the global mechanical strength of the coatings or the rapid depletion of the lubricant element from the coating by out diffusion to the contact zone.

In this talk an overview of the influence of the addition of lubricant elements to Ti-Si-N system will be presented. The coatings were deposited by conventional magnetron sputtering as well as by using HiPIMS power supplies. The importance of the type of the structure of the deposited coatings (nanocomposite or supersaturated solid solution) on their thermal stability, including oxidation resistance, will be discussed based on the diffusion of the lubricant elements. A comparison of the mechanical properties of the coatings deposited by both methods will be performed and the results will be interpreted based on the (micro)structure and residual stresses. Results on the tribological behaviour achieved by tests at room and high temperatures (up to 900 ºC) against different balls (steel, alumina and Ti-alloy) will be presented and commented. Generally, results show that a decrease of the mechanical performance of the coatings is obtained with that elements addition. However, in relation to tribological performance, significant improvements could be reached although under specific testing conditions (type of ball, temperature, …). In many cases, no improvements were observed.

10:20am **SE+AS+SS-FrM-7 Development of Ultra-thick CrAlAgN Coatings by HiPIMS for Self-lubrication at Elevated Temperatures*, Jianliang Lin,*** Southwest Research Institute*; X Zhang,* Southeast University, China

The pursuit of advanced coating systems to provide sufficient oxidation resistance and self-lubrication for high temperature tribological application continues. One of the approaches is to dope traditional hard transition metal nitride coatings with solid lubricants, e.g. Ag, Au, which diffuses towards coating surface to provide lubrication at elevated temperatures. However, the long term performance of these self-lubricating coatings at high temperatures in ambient air is limited by the rapid out diffusion of Ag, which is strongly affected by many factors, e.g. the volume fraction of the dopant and the density of the coating. It is expected that dense coating structure combined with increased coating thickness is helpful for achieving long term lubrication performance. In this paper, ultra-thick CrAlAgN coatings (50 µm) are deposited on steel and cement carbide substrates using high power impulse magnetron sputtering (HiPIMS) by carefully control the processing parameters. The structure and composition of the coatings were first tailored to achieve a combination of good adhesion, high density and good mechanical strength with HiPIMS deposition. The Ag concentration in the coatings is varied in the range of 3-10 at.%. For the coating performance, the oxidation resistance of the coating were studied in ambient air using isothermal test. The high temperature wear resistance of the coating was measured using a high temperature pin-on-disc tribometer in the ambient air from 500 °C to 900 °C. It was found that Ag doping degrades the mechanical strength and oxidation resistance of the CrAlN coatings, but the ultra-thick CrAlAgN coating show robust self-lubricating performance at high temperatures.

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