Surface Engineering
Room 201 - Session SE-MoA

Coatings for Extreme Environments: Wear Resistant, Lubricious, Anti-corrosive, High Temperature Coatings

Moderator: W. D. Sproul, Reactive Sputtering Inc.

2:00pm **SE-MoA1 Coatings and Surface Engineering for Tough Applications**, ***A. Inspektor***, Kennametal Inc. **INVITED**

A functional surface is an engineered system consisting of substrate and coating designed to work together. From a 50 µm thick diamond layer on cutting tools to a few atoms thin protective barrier on hard drives, a functional surface is a critical component in many new high technology products. It is the first line of defense of the coated part and thus, it is absolutely vital to the performance and to the reliability of the part in tough applications. This paper will present and critically review principles of surface engineering for cutting tools and wear parts. An emphasis will be on the design and preparation of the working surface as illustrated by case studies from diamond-coated cutting tools, thermal barriers for automotive and aerospace engines, concepts in cBN deposition, and recent developments in the field of nano-layer and nano-composite superhard films.

2:40pm **SE-MoA3 Influence of the Interface Composition on the Corrosion Behavior of Unbalanced Magnetron Grown Niobium Coatings on Steel**, *C. Schönjahn,* ***H. Paritong***, *W.-D. Münz,* Sheffield Hallam University, UK; *I. Petrov, R.D. Twesten,* University of Illinois, Urbana

In general niobium is well known as a chemically extremely stable material. However the corrosion performance of 0.5 to 1 µm thick , unbalanced magnetron (UBM) grown niobium coatings on steel substrates depends significantly on the in vacuo etching pretreatment of the substrates prior to coating and on the chemical composition of the steel substrate. Corrosion tests, TEM and STEM analyses have shown that a dense fine grained partially implanted 5-10 nm thick niobium interface layer formed during the metal ion etching pretreatment is paramount to protect the steel substrate thoroughly against corrosion in chlorine containing aqueous electrolytes, whereas the pretreatment with Ar @super +@ and Cr @super +@ ions leads to inferior corrosion results. Moreover the energy of the impinging Nb @super +@ ions used during the etching process plays an important role. Maximum pitting potential and minimum corrosion currents were found for bias voltages between -600 and -900 V. In summary the results suggest that the UBM deposited Nb coatings are not completely dense although no evidence for the presence of voids has been found by TEM analysis and that the major justification for niobium as corrosion barrier depends on the existence of the thin interface layer generated by high energetic ion bombardment during the etching step. The UBM deposited coating (U@sub s@=-75V) acts therefore only as an itself chemically stable mechanical spacer protecting the thin interface layer against mechanical damage.

3:00pm **SE-MoA4 Oxidation Resistance of NiAl and NiAl-AlN Coatings Deposited by Magnetron Sputtering**, ***D. Zhong***, Colorado School of Mines; *A.M. Peters,* Los Alamos National Laboratory; *J.J. Moore, G.G.W. Mustoe,* Colorado School of Mines; *J. Disam, S. Thiel,* Schott Glas, Germany

It is well known that NiAl exhibits excellent oxidation resistance and it shows improved cyclic oxidation resistance when NiAl-AlN composite is used. In this work, NiAl and NiAl-AlN coatings have been deposited from a NiAl compound target by using RF magnetron sputtering technique. The oxidation behaviors of NiAl and NiAl-AlN films were studied using a Netzsch Simultaneous Thermal Analyzer (STA409C) and Rutherford Backscattering Spectrometry (RBS). Their structures and microstructures were characterized using x-ray diffraction (XRD), scanning electron microscope (SEM) and transmission electron microscope (TEM). It was shown that they are excellent oxidation resistant coatings. In this paper, their oxidation rates and mechanisms will be discussed together with their structure observations as well.

3:20pm **SE-MoA5 Aspects of Surface Engineering in the Automotive Industry**, ***Y.T. Cheng***, General Motors R&D Center

The manufacturing of an automobile is to a large extent the making of engineered surfaces on several length scales using a variety of processing techniques. In this presentation, we will summarize aspects of our recent work related to surface engineering. Examples include the preparation and characterization of nanocomposite thin films consisting of metal-metal and metal-ceramic materials; their tribological properties and potential application as low-friction and wear resistant coatings for electrical connectors will be discussed. Other examples include the investigation of thin films for sensors, battery electrodes, and catalysts. We will also review our work on modeling indentation measurements. Although significant progress has been made in surface engineering, it is still largely a "trial-and-error" process. We will illustrate with examples the needs for: (1) reducing the cost and improving the reproducibility of tribological coatings, (2) better characterization techniques for mechanical property measurements at the nano- and micro-meter scales, and (3) design guidelines and models based on the fundamental understanding of the relationships between the structure, property, and performance of engineered surfaces.

3:40pm **SE-MoA6 Tribological Performance and Initial Finite Element Modeling of Reactively Sputtered Single and Multi-layer Chromium Nitride Thin Films**, ***S.L. Rohde***, *L. Olson, S.M. Aouadi,* University of Nebraska; *D.M. Mihut,* Multi-Arc Scientific Coatings; *B. Neville,* Iowa State University; *D.M. Hornyak,* University of Nebraska

Tribological properties of Cr-N based single- and multi-layer thin films are compared with FEA modeled stress fields under similar loading, to evaluate the feasibility of "building-in" load support, with alternating hard/soft film layers to optimize performance on both traditional tool steels and more compliant substrates. The first phase involved the deposition and evaluation of coatings on substrates of both hardened A2 tool steel and 2024-alloy aluminum. Next, the wear behavior was assessed using pin-on-disk (PoD) tests, performed unlubricated at 40 to 50% humidity using alumina and/or tungsten carbide 'pins'. The wear was reduced in most cases, with the multi-layered structures performing best on all substrate materials. PoD tests on the A2 tool steel substrates, favored the hardest thin film structures; however, these same films did not perform as well on the more compliant Al-substrates. For the Al-substrates, neither the stiffest nor the most compliant films excelled, instead multi-layer films with alternating hard/soft structures designed to provide a more graded compliance from the substrate up to the rigid top layer yielded the best results. In this case, wear rates were reduced by as much as much as three orders of magnitudes over uncoated 2024 Al. In the final stage, finite element modeling studies have been initiated to try to understand the behavior of these multilayered coating/substrate combinations under specific loading conditions. First generation models are matched to their respective wear systems and the results compared. These models will then be used to guide the development of second generation coatings, that will be used to verify and improve the efficacy of the models. The goal of the modeling program is thus to facilitate specification and optimization of application specific coating structures into the original component designs.

4:00pm **SE-MoA7 Tribological Performance of a Novel High Wear Resistant 390 Al Alloy Overlay**, ***R.D. Ott***, *C.A. Blue, M.L. Santella, P.J. Blau,* Oak Ridge National Laboratory

A novel process has been developed at Oak Ridge National Laboratory (ORNL) for the production of high silicon (Si) containing aluminum (Al) alloy surface layers (overlay) on Al alloys. The main purpose of the overlay is to improve the wear resistance of the underlying alloy. The process is versatile enough to place the overlay only in critical areas, thus, greatly reducing the cost of a component. Instead of manufacturing a component from expensive high Si content 390 Al alloy, the component could be manufactured from an inexpensive alloy, such as 319 Al alloy, and the 390 Al alloy overlay could be placed in essential areas were high wear resistance was required. Test specimens comprising of 390 Al alloy overlays on 319 Al alloy have been processed to mimic bulk 390 Al alloys. Pin-on-disk wear tests have been performed, following ASTM standards, to quantify the wear resistance of the 390 Al alloy overlay with that of bulk 390 Al alloy. Wear tests have also been performed on bulk 319 Al alloy as a baseline. Lubricated and non-lubricated pin-on-disk wear tests were conducted utilizing 440C stainless steel and 52100 steel balls as the pin material. Also evaluated were the frictional forces during the wear tests, scratch hardness, microhardness, and the Hertzian contact pressures. From the tests conducted, the 390 Al alloy overlay shows potential as a replacement of bulk 390 Al alloy for high wear resistant applications.

4:20pm **SE-MoA8 Mechanical and Tribological Properties of Substoichiometric Oxide and Superstoichiometric Carbide Coatings for Wear Reducing and Lubricating Applications**, ***St. Bärwulf***, *E. Lugscheider, K. Bobzin,* University of Technology Aachen, Germany

The tungsten and vanadium oxides are promising to be usable as solid lubricants at elevated temperatures because of their ability to form non stoichiometric Magnéli-phases with reduced shear strength. So far they

were mainly investigated as powdery material or as a component of ceramics for tribological or machining applications. As a matter of fact metal-oxides are interesting for tribological insets at atmospheric conditions because of their expected oxidation stability, hardness and low adhesion against the counterbody. For low temperature insets carbon containing coatings are meanwhile widely spread in numerous applications. Because of their phase generation / transition the zircon- and hafnium-carbon systems offer a very interesting possibility to deposit graded coatings with self-adapting properties in dependance on the external mechanical load and the contact conditions. This self-adapting effect will be shown exemplarily for a hydraulic component after an inset under load in relative motion. The presentation will report about the mechanical and tribological properties of these coatings. Further possible ranges of applications will be deduced from the fundamental characterization and results of concrete insets (e.g. machining) shown. Therefore the coatings were analyzed by various testing methods to characterize the tribological, mechanical and structural properties, like contact angle measurements, SEM, scratch testing, nanoindentation, XRD and pin on disk.

4:40pm **SE-MoA9 Thin Film Disk Contact Start/stop Durability Failure Model: Subcritical Interfacial Crack Growth***, **R.L. White**, V. Raman,* IBM Corporation

Analogous to fatigue failure in bulk materials, contact start/stop (CSS) failure of thin film disks is modeled as the progressive growth of interfacial cracks resulting from the cyclic tractions applied by intermittent slider-disk contact. Interfacial cracks eventually reach a critical dimension, resulting in film fracture or spallation and catastrophic failure of the head-disk interface. There are two bodies of evidence which support such a model. The first derives from scratch adhesion testing of mechanically textured disk media. The scratch data demonstrate that the same weibul statistics that can be fitted to CSS failures also describe the distribution of critical loads necessary to produce delamination of the disk metallurgy. Furthermore, a number of cases can be cited in which the critical loads can be correlated to start/stop durability, including the effects of hydrogenation on the start/stop durability of CHx overcoats. Secondly, this model provides for the semi-quantitative prediction of the effects of head-disk interface parameters which are in general agreement with empirical studies. The tractions applied at the head-disk interface are predicted to diminish with distance from the interface with a 1/d dependence. Since subcritical crack growth rate follows a power law relationship to stress intensity, start/stop failure statistics would be expected to show a power law dependence on carbon thickness. Data are presented demonstrating CSS life is proportional to the 3rd power of carbon thickness. The effects of CSS test temperature and slider size can also be rationalized based on the above model for CSS failure.

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