Advanced Surface Engineering Division
Room A215 - Session SE-ThA

New Challenges and Opportunities in Surface Engineering

Moderators: Jolanta Klemberg-Sapieha, Polytechnique Montreal, Matjaz Panjan, Jozef Stefan Institute, Slovenia

2:20pm **SE-ThA1 Evaluating Electro-Mechanical Reliability using In-Situ Methods***, M.J. Cordill, O. Glushko,* Erich Schmid Institute of Materials Science, Austrian Academy of Sciences, Austria*; **Patrice Kreiml,*** Montanuniversitaet Leoben Erich Schmid Institute for Materials Science, Austria **INVITED**

Electrical, mechanical and interfacial properties of thin metal films on compliant polymer substrates are important to understand in order to design reliable flexible electronic devices. Thin films of Cu and Au on polyimide and polyethylene terephthalate substrates were examined for their use as interconnects in flexible electronic devices. Using in-situ tensile straining with atomic force microscopy (AFM), X-ray diffraction (XRD), and confocal laser scanning microscopy (CLSM) mechanical and interfacial behavior can be examined. AFM and CLSM can provide information about crack spacing and film delamination, while XRD experiments are utilized to determine the lattice strains and stresses present in the films. If these in-situ techniques are combined with in-situ 4-point-probe (4PP) resistance measurements, the influence of the mechanical damage on the electrical properties can be correlated. This combination of multiple in-situ investigations are particularly useful when studying the electro-mechanical behavior under cyclic loading conditions where some materials can have an improvement of the electrical conductivity after a few hundred cycles. Mechanism behind these phenomena as well as methods to measure the adhesion of metal-polymer interfaces found in flexible electronic devices will be discussed.

3:00pm **SE-ThA3 Surface Engineering for Bearing Applications: Present Status and (Near)-Future Needs***, **Esteban Broitman,*** SKF - RTD - Research & Technology Development Center, Netherlands **INVITED**

Machines with rotating components usually rely on bearings to reduce friction in moving its parts around a fixed axis. The increasing demand for more precise bearings to lower power consumption and heat generation, while simultaneously support increasing applied loads and/or higher speeds, has given place to the use of surface engineering processes.

In the case of bearings, it is widely accepted the advantages of using coatings as the surface process to improve its performance. During the last three decades, advanced coatings have enjoyed a growing interest in several industrial applications because they can be engineered to provide different properties like electrical insulation, low friction, and resistance to corrosion, surface initiated rolling contact fatigue, abrasive wear, and plastic deformation. The main surface engineering processes to deposit these coatings include traditional technologies such as dipping and liquid spraying, chemical conversion, galvanizing and electroless processes, as well as more sophisticated technologies such as thermal spraying, physical vapor deposition, diffusion, and ion implantation. However, the special characteristics of the bearing steel and the need to limit the deposition costs reduce the number of methods that can be practically used.

In this talk I will first introduce the four main areas where coatings can contribute to improve the performance of bearings made of standard bearing steel: lower friction, decreased wear, corrosion resistance, and electrical insulation. For each area I will review which coatings are industrially used, their possible industrial deposition methods, and their main mechanical and tribological properties. Examples of SKF coatings used to extend maintenance and life expectancy of specialized bearings will be described, like NoWear® (carbon-based nanostructured coating), Black Oxide (iron oxide conversion film), INSOCOAT® (aluminum oxide coating), and manganese phosphate films. I will finish the presentation visioning which the (near)-future needs of specialty surface-treatment coatings are in response to bearing application challenges, including a novel fifth area of sensorized coatings.

4:00pm **SE-ThA6 *In situ* Scanning Electron Microscopy based Uniaxial Compression of sub-micrometer-size NbC(100) Single-crystalline Pillars***, A. Aleman, K. Tanaka, H. Zaid, J.-M. Yang, **Suneel Kodambaka,*** University of California, Los Angeles

Cubic group 4 and 5 transition-metal carbides (TMCs), such as HfC and TaC, are hard (>20 GPa) and strong (moduli >270 GPa) solids with high melting points (> 2900 K) that exhibit superior strengths at elevated temperatures and excellent resistance to wear, ablation, and corrosion. They are attractive for applications in cutting tools, hard protective coatings, advanced propulsion systems, spacecrafts, rockets, and hypersonic jets that operate under extreme environments, e.g. at ultra-high temperatures (> 2000 K) and highly corrosive atmospheres. The realization of enhanced ductility, especially at low temperatures could potentially enable new applications for this class of materials. Our recent efforts have focused on understanding the mechanical behavior of group 5 TMC single-crystals, VC, NbC, and TaC.

Here, we report on the room-temperature mechanical behavior of 100-oriented NbC single-crystalline pillars of diameters between 330 and 830 nm. We prepared the pillars via focused ion beam milling of bulk, commercially-available, NbC single-crystals. We carried out uniaxial compression of the pillars using Hysitron PI-85 picoindenter *in situ* in a scanning electron microscope . We find that all the pillars exhibit plastic deformation with strains up to 26%. Load-displacement curves obtained during the compression tests reveal multiple displacement bursts, indicative of sustained slip. Interestingly, yield strengths vary non-monotonically with pillar diameter between 8 GPa and 12 GPa and by up to 40% among the pillars of the same diameter. From the post-compression images of the pillars, we identify {110}<110> and {111}<110> as the two likely slip systems operating within these pillars. We suggest that the observed size-dependence in NbC(100) pillars is a consequence of the activation of these two slip systems. We observe a similar size-dependence in VC(100) pillars based upon which we suggest that the observed mechanical behavior is characteristic of group 5 TMCs.

4:20pm **SE-ThA7 Thermal Stability of MoNbTaVW High Entropy Alloys Thin Films Deposited by Cathodic Arc***, A. Xia, **Robert Franz,*** Montanuniversität Leoben, Austria

High entropy alloys (HEAs) are a new emerging class of materials typically consisting of 5 to 13 metallic elements in an approximately equimolar ratio. Studies conducted on HEA bulk materials revealed promising combinations of properties, such as high strength, ductility, corrosion resistance, wear resistance, hardness, low diffusion and thermodynamic stability. While research on bulk high entropy alloys has seen quite a boost over the past years, investigations on thin films are still a relatively unexplored area.

Within the current work, the thermal stability of refractory MoNbTaVW HEA thin films was studied up to an annealing temperature of 1600 °C. The thin films with a thickness of about 1 µm were synthesized on sapphire substrates by cathodic arc deposition. The samples were annealed in a vacuum furnace for 1 hour at temperatures ranging from 1000 to 1600 °C in steps of 100 °C. After annealing, scanning electron microscopy images were recorded indicating changes in the film morphology at 1200 °C and above. Analysis by X-ray diffraction revealed the formation of new phases at 1500 °C. Nanoindentation tests were performed to assess possible changes in the mechanical properties of the films. A decrease from about 20 GPa for the as-deposited films to about 9 GPa after annealing at 1600 °C was noticed. The electrical conductivity of the MoNbTaVW thin film slightly decreased due to annealing as the measured resistivity increased from $5 \cdot 10^{-7}$ Ωm to $1.5 \cdot 10^{-6}$ Ωm.

4:40pm **SE-ThA8 Erosion Resistant Coatings Inside Narrow Tubes to Protect Aircraft Engine Components***, A. Kilicaslan, O. Zabeida, E. Bousser, L. Martinu, **Jolanta Klemberg-Sapieha,*** Polytechnique Montreal, Canada

There is an ever-growing interest in the use of functional coatings to protect surfaces of materials and workpieces against harsh environments such as corrosion, abrasion or solid particle erosion (SPE), making surface engineering solutions a very attractive balance between performance and cost. Numerous vapor-based fabrication techniques have been developed, namely PVD, CVD and PECVD, that can be used to achieve high hardness and high wear resistance, while being compatible with substrate materials such as metals, and different substrate shapes. This is increasingly important in the case where there is a need for protective coating solutions for inner surfaces of tubular components, such as parts of aircraft engines, oil pipelines, mining components, and numerous others. Specifically, certain aircraft diffusers are designed to conduct the air to the combustion chamber by means of many narrow gas inlets arranged around a circular frame. In such case, SPE arising from dust particles and volcanic ashes present in the air can result in an increase of the gas inlets diameter, leading to back streaming of air into the compressor (known as the compressor surge), which can give rise to significant aircraft engine damage and catastrophic consequences.

In response, we propose a novel Non-Line-Of-Sight (NLOS) technique to coat the inner parts of non-linear surfaces and cavities with hard, wear- and erosion-resistant coatings possessing high erosion resistance, hardness significantly higher than the hardness of the particles impacting the surface, as well as a large thickness (preferably 8 µm and more).

Specifically, we review, study and demonstrate the fabrication process of hard SPE-resistant TiN protective coatings on the inner surfaces of narrow tubes using a non-obvious NLOS approach yielding a uniform film thickness and properties along the tube axis (better than 20%). The deposition process indicates the importance of applying pulsed-DC PECVD, when uniform hard TiN films are prepared at low-frequency in the several kHz range. The TiN films (about 12 µm thick), exhibit high hardness and Young's modulus (25 and 225 GPa, respectively), corresponding to the (111) preferred crystallographic orientation. We show that the SPE resistance on the inner surface decreased by a factor of more than 15 compared to the bare substrate, and that the process is well suited for the protection of aerospace, manufacturing, 3D printed and other critical components with a complex shape of inner surfaces.

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