## Surface Engineering - Applied Research and Industrial Applications
## Room Sunrise - Session G2

### Components Coatings

**Moderators:** Kenji Yamamoto, Kobe Steel Ltd., OsmanL. Eryilmaz, Argonne National Laboratory, USA, Jolanta Ewa Klemberg-Sapieha, Polytechnique Montreal

1:50pm **G2-2 Advanced Metal/Ceramic Nano-multilayers for Joining Applications: Interplay between Nano-confinement, Stress Relaxation and Environmental Conditions***, **Mirco Chiodi**, C Cancellieri, F Moszner,* Empa, Laboratory for Joining Technologies & Corrosion, Switzerland*; M Andrzejczuk,* Warsaw University of Technology, Poland*; J Janczak-Rusch, L Jeurgens,* Empa, Laboratory for Joining Technologies & Corrosion, Switzerland

The industrial demand to manufacture complex, heterogeneous devices has grown exponentially. Such devices typically comprise various materials with different heat sensitivities and thermal expansion coefficients. Thus, novel approaches towards joining of complex multi-materials at ever-reduced temperatures are emerging. Among the others, a promising strategy involves the use of nanostructured brazing fillers in the form of coatings consisting of Nano-MultiLayers (NMLs) of metallic brazing filler and a chemically inert barrier. The interplay between spatial confinement, internal stress gradients and the processing environment can stimulate phase-transitions and/or enhanced kinetics associated with a significant outflow of the confined metallic brazing filler to the surface at reduced temperatures. This phenomenon could be exploited for joining materials well below the melting point of the bulk constituents.

Here, we present a comprehensive investigation of the microstructural evolution of (Ag/AlN)5nm/10nm NML coatings upon heating in air. SEM/TEM results evidence the strong migration of Ag from the inner part of the NML to the surface. Silver particles as large as 1 µm are found after a heat treatment in air up to 420 °C. XRD characterization and pole figures confirm that Ag and AlN are initially strongly textured. The in-plane texture is partially lost upon heating in air, as a consequence of the Ag migration and the partial oxidation of AlN. The microstructural evolution of the Ag/AlN NML during annealing was monitored by real-time XRD collected at the synchrotron. Beyond this temperature, a strong increase in the Ag coherency domain is registered. Such increase correlates with the Ag particle appearing on the surface and subsequently coarsening. The average stress state in the Ag layers has been qualitatively evaluated using the real-time XRD data. The results indicate an accumulation of (thermal) stress between 200-280 °C which is then released at higher temperatures, triggering the massive Ag migration. Identical experiments carried out in vacuum or in absence of multilayered structure indicate that no Ag migration takes place. To elucidate the crucial role of oxygen on the Ag mobility at low temperatures, an extensive XPS analysis was carried out on samples heated at different temperatures (from 200 °C to 420°C). The results indicate that oxygen is penetrating through the NML structure and (partially) reacting with both AlN (forming AlOx) and Ag (being adsorbed and/or incorporated at Ag layers surface). The adsorption and dilution of oxygen in Ag can strongly enhance its atomic mobility, thus further easing its relocation on the NML surface.

2:10pm **G2-3 Coatings for the Aerospace Industry***, **Jeffrey Lince,*** The Aerospace Corporation, USA **INVITED**

Coatings are of critical importance to both aircraft and spacecraft. However, environmental requirements for coatings between the two vary considerably. Coatings used to protect turbojet engines must operate in air at a wide range of temperatures from ambient to greater than 1200°C. In contrast, coatings used on spacecraft may be required to achieve their function in air during prelaunch storage, and also on orbit, i.e., in vacuum, at lower temperatures, and in a potentially radiation-rich environment. This talk will provide a survey of coatings techniques for aircraft and spacecraft, concentrating on areas where improvements are needed. For example, superalloys are used to maintain strength at elevated temperatures in aircraft applications, but compatible coatings are required to form thermal barriers, and to minimize corrosion and fatigue. Thermal spray coatings are being used extensively for this purpose. In addition, thermal spray and PVD coatings are used to coat ceramic fiber cloth with metals to form advanced metal-matrix composites (MMCs) that are low weight and exhibit superior materials properties. Solid lubricating/antiwear coatings in aircraft and space applications often involve different materials: $CaF_2$ and metal oxides provide low friction and wear in air at elevated temperatures, while $MoS_2$ is preferred at low temperatures in vacuum. Chromate coatings are used for corrosion protection on both aircraft fuselages and spacecraft surfaces, but improved performance can be met with more modern coating materials like rare earth salts, sol gel organic-inorganic composites, and resin composites. In this talk, current research being done in order to push coating performance to meet continually increasing requirements will be discussed.

2:50pm **G2-5 Triboactive CrAlN+X Hybrid dcMS/HPPMS PVD Nitride Hard Coatings for Friction and Wear Reduction on Components***, K Bobzin, T Brögelmann, **Christian Kalscheuer,*** Surface Engineering Institute - RWTH Aachen University, Germany

Increasing environmental awareness and energy costs are major driving forces behind the development of energy efficient machines. Simultaneously, increased energy efficiency often leads to higher power densities. The consequences are load spectra which often exceed the load carrying capabilities of the base material and therefore higher wear rates and reduced life times. Therefore, coatings for the application on highly loaded components were developed. Besides diamond-like carbon (DLC) coatings, nitride hard coatings deposited by physical vapor deposition (PVD) show a high potential for wear reduction on machine components. However, regarding friction reduction in lubricated tribological contacts, nitride hard coatings still exhibit a high demand for research since state-of-the art lubricants are tailored to interact with steel surfaces in order to form friction reducing tribolayers. Therefore, the addition of tribo effective elements (X) into nitride hard coatings is a promising approach to enhance tribological interactions with lubricants and to reduce friction. In order to deposit PVD coatings on complex geometries with increased mechanical properties, the high power pulsed magnetron sputtering (HPPMS) technology shows high potential. The aim of the paper is the analysis of the tribological interaction between the nitride hard coating (Cr,Al)N+Mo and lubricants. Therefore, a mineral base reference oil and a mineral oil doped with a sulphur additive were investigated regarding interactions with the coatings under tribological conditions. The coatings were deposited in a low temperature T ≤ 200 °C hybrid PVD coating process on case hardened steel AISI5115 (16MnCr5E). Hybrid PVD coating processes allow the combination of direct current magnetron sputtering (dcMS) and HPPMS. The coating and compound properties were investigated. The tribological behavior of the coatings was tested in a pin on dics (PoD) tribometer against inert ceramic $Si_3N_4$ counter bodies to ensure that tribologial interactions can only occur due to reactions between the coatings and the lubricant. The uncoated case hardened steel AISI5115 (16MnCr5E) and a (Cr,Al)N coating were investigated as reference. The tests were conducted at temperatures T = 90 °C and T = 130 °C at Hertzian contact pressures $p_H \approx$ 1,600 MPa and $p_H \approx$ 1,900 MPa. Under the given tribological conditions a friction reduction was achieved by adding the tribo effective element Mo into the coatings. Raman spectroscopy revealed that $MoS_2$ was formed in-situ during the tribological tests. The investigated (Cr,Al)N+Mo coatings are therefore a promising approach for friction reduction in highly loaded tribological systems.

3:10pm **G2-6 Tribological Performance of PTFE Based Composite Seal Materials Against Diamond Like Carbon and Catalytically Active Nitride Based Nano-composite Coatings***, **OsmanL. Eryilmaz**, G Ramirez, A Erdemir,* Argonne National Laboratory, USA

Natural gas (NG) consumption has been grown rapidly during the last decade, and NG production is projected to further increase by 44% through 2040. Consequently, the potential for methane emission (which can deter GHG benefits of using NG) is also expected to increase throughout the supply chain. Accordingly, the NG industry is facing tough challenges toward mitigating methane emissions in the form of not only adopting new low-emission gas compression technologies but also upgrading or enhancing the currently installed compressors in the field. NG industry uses two types of compressors in the production, delivery and storage of NG. Most common one is the reciprocating NG compressors which account for the largest amount of leakage of methane. Primary leak source of those compressors are wear and scratches on rod and seal material surfaces in piston rod packing systems. One approach is to apply hard coatings onto rod surfaces to prevent wear on the rod side, however it could be detrimental on the delicate Teflon based counter face seal side.

New coatings and surface modification techniques are in need to prevent wear on both surfaces. One approach would be to develop a hard coating that generates tribo-films that beneficial to Teflon based seal side as well, this would minimize wear on both sliding surfaces, or another approach would be to use already known solid lubricant coating such as diamond like carbon. Accordingly, in this paper, we concentrate on the friction and wear performance of DLC, and catalytically active nano-composite nitride based coatings against PTFE type seal materials filled with different fillers (Carbon, MoS2, glass, etc.). A series of vanadium nitride – copper nano-composite, and hydrogenated DLC films were prepared using high power impulse magnetron sputtering (HPIMS). The films were grown on 52100 steel substrates for tribological tests. X-Ray Diffraction (XRD), raman Spectroscopy, nano-indentation techniques were used to characterize the structural, mechanical and chemical nature of the resultant coatings. Bench-top tribological tests were conducted by using oil lubricated reciprocating test rig. Overall, the effect of sliding speed, contact pressure, type of PTFE fillers on the tribolocigal behavior of coatings were investigated. Both nitride and carbon based coatings improved the wear performance of the system depending on the type PTFE composite counter-face used. At the end of each test, confocal raman was used to evaluate sliding interfaces and any structural changes resulting from the tribological tests to shed more insight into the possible mechanisms responsible.

# Author Index

## Bold page numbers indicate presenter