Surface Engineering - Applied Research and Industrial Applications
Room Palm 1-2 - Session IA2-1-WeM

Surface Modification of Components in Automotive, Aerospace and Manufacturing Applications I

Moderators: Satish Dixit, Plasma Technology Inc., USA, **Susumu Kujime**, Kobe Steel Ltd., Japan

8:00am **IA2-1-WeM-1 Micro-Impact Testing to Develop Multilayer Coating Systems with Enhanced Durability Under Cyclic High-Stress Contact***, Ben Beake [ben@micromaterials.co.uk],* Micro Materials Ltd, UK*; Tomasz Liskiewicz,* Manchester Metropolitan University, UK*; Sam McMaster,* Anglia Ruskin University, UK*; Daniel Tobola,* Lukasiewicz, Poland*; Luis Isern, John Nicholls,* Cranfield University, UK*; Hannah Zhang, Mark Gee,* National Physical Laboratory, UK **INVITED**

The lifetime of components operating in harsh environments subjected to repetitive contacts in high performance manufacturing operations, gas turbines and automotive engines can be extended by the application of advanced multilayer coating systems. These coating systems need to combine high hardness with resistance to fracture. The cyclic nano- or micro-scale impact test has been shown to be a convenient test method to rank coating resistance to fracture, with coating performance in the test with typically a 1:1 correspondence to the application performance.

In this presentation we will provide an overview of the technique and describe several recent technical developments including (1) higher data acquisition for multi-metric analysis of every impact (2) inclined impact to combine shear and compression forces (3) impact at elevated temperature (4) spatially distributed impact, and show how these are being used in testing (i) thermal barrier coatings (TBCs) in gas turbines (ii) DLC coated steel components in automotive engines (iii) PVD coated steel and coated WC-Co cutting tools.

The multi-metric analysis reveals significantly more about the deformation and wear behaviour in the test than the impact depth alone, showing that in some cases the % dissipated energy in cyclic impact can act as an “early warning signal” for failure as it can be sensitive to the initiation and growth of sub-surface crack networks before crack coalescence and fracture occurs. To simulate applications where cyclic impact events are not perpendicular to the surface inclined impact tests have been performed which have, for example, revealed markedly different effects on the durability of DLC coatings and TBCs. Reasons for these differences will be discussed. To replicate the spatial distribution of multiple impacts that occur when a coated component is subjected to solid particle erosive wear the method has been adapted to produce controlled impacts at different statistically-distributed locations on the sample surface. Tests on the TBCs 7YSZ and gadolinium zirconate clearly showed that the spatially-distributed micro-impact test could replicate differences in erosion resistance and also reproduce the main damage mechanisms and surface morphology that occur.

8:40am **IA2-1-WeM-3 From Lab to Industry: Scaling Atmospheric Plasma Coatings for Metal Protection Against Corrosion***, Daphne Pappas [daphne.pappas@plasmatreat.com],* Plasmatreat USA **INVITED**

Magnesium and aluminum alloys are extensively used in the automotive, aerospace and other industries due to their robustness, lightweight, and excellent weight-to-strength ratios. The manufacturing of lightweight structural components for aircraft and various types of vehicles leads to improved fuel efficiency and lower greenhouse gas emissions. However, long term exposure to moisture, pollution, salt and other harsh environments make them susceptible to corrosion. Common mitigation strategies involve surface treatments like ion implantation and protective coatings that can enhance the corrosion resistance of common metals.

In the first part of this talk, an overview of plasma-based coating methods for corrosion protection will be presented. For decades, low pressure plasma systems were employed in the deposition of thin coatings on steel, aluminum and other metals. While the coatings provided significant improvement in corrosion protection, vacuum chambers are often limited in volume, making it difficult to treat large or irregularly shaped parts efficiently.

In recent years, atmospheric pressure plasma systems are preferred for scalable, continuous, and flexible surface treatments. In the second part of this work, the plasma-assisted, large area deposition of dense, organosilicon coatings on Al 6061, AM60 and AZ91D Mg alloys using atmospheric pressure plasma jets will be presented. For the deposition process, clean dry air was used as the plasma generating gas, along with 2 types of siloxane precursors. The process was fully automated, as the plasma jets were moved over the substrates at constant speed with the assistance of a robotic system.

Results from the analysis of coatings with thicknesses ranging from 200nm to 1200nm will be shown. The electrochemical characterization involved immersion of the Mg alloy substrates in a 3.5wt.% NaCl solution, whereas the aluminum substrates were exposed to highly corrosive HCl solutions. Multi-scale image characterization and chemical analysis was performed using scanning electron microscopy (SEM) equipped with energy dispersive X-ray spectrometry (EDS) and scanning transmission electron microscopy system. More information correlating the plasma process parameters to the elemental composition, thickness and corrosion resistance of the coated metals will be presented.

Overall, large area plasma deposition enables uniform, scalable application of anti-corrosion coatings on metal surfaces, making it ideal for industrial components like automotive and aircraft panels. Its atmospheric operation allows integration into continuous production lines, reducing costs while enhancing durability and surface protection.

9:20am **IA2-1-WeM-5 Directed Energy Deposition of Bronze Coatings on Aluminium Substrates: Microstructure, Phase Evolution, and Process Optimization***, Christoph Witte [christoph.witte@fh-kiel.de], Claus-Henning Solterbeck,* University of Applied Science Kiel, Germany*; Hannes Freiße,* Kugler Bimetal SA, Switzerland*; Johannes Wiesheier, Thomas Rubenbauer,* Schlenk Metallic Pigments GmbH, Germany*; Andreas Ebert, Jürgen Barz,* Schmelzmetall Deutschland GmbH, Germany*; Jana Schloesser,* University of Applied Science Kiel, Germany

With the increasing demand for efficiency and sustainability in aerospace applications, the development of lightweight parts represents a critical challenge. This study presents an integrated approach that covers the entire process chain, from alloy and powder development to the production of functional components, made possible through close collaboration between a research institute and industrial partners. Bronze coatings are applied onto aluminium substrates using a laser powder based Directed Energy Deposition (DED) process, aiming to combine low weight with enhanced wear resistance for the production of sliding bearings.

The metallurgical interaction between aluminium and copper-based alloys is highly complex. In addition to differences in physical properties such as thermal expansion, melting point and diffusion behaviour, brittle intermetallic phases tend to form at the interface. These phases often act as crack initiation sites and can lead to delamination.

In this work, bronze coatings are deposited on aluminium substrates using a powder-based Directed Energy Deposition (DED) process. Prior to the deposition, the aluminium substrates undergo appropriate surface preparation, and post-deposition heat treatments are applied to optimise adhesion and coating properties. The resulting microstructure and phase formation at the interface are investigated. Furthermore, this study identifies critical process parameters that affect coating quality and discusses strategies to mitigate interfacial defects.

This study demonstrates the potential of laser-powder-based DED process for the fabrication of lightweight, wear-resistant sliding bearings, and provides valuable insights into the application of copper-based coatings on aluminium substrates for a variety of applications, particularly in the aerospace sector.

9:40am **IA2-1-WeM-6 Plasma Electrolytic Oxidation Coatings on Mg Alloy AE44 Prepared from Mixed Aluminate-silicate Electrolytes***, Tianyi Zhang [Zhang4x3@uwindsor.ca], Ran Cai, Xueyuan Nie, Henry Hu,* Department of Mechanical, Automotive and Materials Engineering, University of Windsor, Canada

Magnesium–aluminum alloys are increasingly utilized in areas requiring lightweight materials, such as the automotive industries and humanoid robotics, due to their advantageous properties. However, their relatively low strength, hardness, and corrosion resistance limit their broader engineering applications. To address these shortcomings, surface modification techniques such as plasma electrolytic oxidation (PEO) are employed to form protective oxide layers that enhance surface performance. In previous studies, sodium phosphate (Na_3PO_4) solutions were commonly used as electrolytes, while other electrolyte systems have been less frequently investigated. In this study, aluminate–silicate mixed electrolytes with varying concentrations were utilized to fabricate PEO coatings. The surface morphologies were examined using scanning electron microscopy (SEM), and elemental contents were quantified through energy-dispersive X-ray spectroscopy (EDS), the phase compositions were identified by X-ray diffraction (XRD). Furthermore, potentiodynamic polarization, hardness, and indentation tests were conducted to assess the coatings' performance. The results revealed that the addition of silicate to the aluminate electrolyte enhanced the coating growth rate. Moreover, coatings produced from electrolytes with different concentrations exhibited distinct surface morphologies, as well as varying corrosion and indentation resistance.

11:00am **IA2-1-WeM-10 Low-Adhesion Carbon Coatings for the Sustainable Utilization of Geothermal Power Plants***, Yuya Nakashima* ***[nakashima-yuuya@fujielectric.com],*** Fuji Electric Co., Ltd., Japan*; Noritsugu Umehara,* Nagoya University, Japan*; Hiroyuki Kousaka,* Gifu University, Japan*; Takayuki Tokoroyama,* Nagoya University, Japan*; Motoyuki Murashima,* Tohoku University, Japan **INVITED**

Geothermal power generation is one of the renewable power generation systems and they emit only 1 – 3 % CO2 compared to emissions from coal-fired thermal power plants. Additionally, geothermal power plants provide stable electricity supply in contrast to the other renewable power sources such as solar and wind power which fluctuate power outputs depending on time and weather. However, geothermal steam, which is origins to rotate steam turbine, contains much amount of dissolved silica. It precipitates and accumulates on the turbine components and clogs steam flow throats and eventually causes power output drop and frequent maintenance. In this study, Diamond-like Carbon (DLC) is adopted as coating to suppress the silica accumulation on turbine blades. DLC is carbon based thin coating consist of sp2 and sp3 structures and has high chemical stability which may also has low chemical interaction against silica. Hence, chemical structure of DLC to reduce silica adhesion is revealed. To identify chemical structure of DLC on the outermost surface, X-ray analysis fine structure (XAFS) and Elastic recoil detection analysis (ERDA) is employed since outermost surface is quite important for adhesion and chemical structure of DLC completely differ from its bulk to outermost surface. As a result, DLC has lower sp2 fraction can reduce adhered silica amount to 3% compared with that on steel and if DLC has higher sp2 fraction but it also has higher hydrogen content, adhered silica amount is reduced to same level with DLC with lower sp2 fraction. It indicates lower sp2 fraction and higher hydrogen content can reduce silica adhesion. Then, chemical interaction against silica from DLC is revealed by calculating adsorption energy between sp2 structure and silica through ab initio calculation. sp2 structure itself physically adhere to silica, but if it has atomic defect as dangling-bond, adhesion state is changed from physical to chemical adhesion. If that dangling-bonds are terminated by hydrogen atoms, chemical adhesion is changed back to physical adhesion. Hence, adhesion mechanism between DLC and silica as chemical adhesion sites against silica is reduced by reducing sp2 fraction and adhesion state is changed to physical adhesion by increasing hydrogen content is proposed. Finally, DLC coated turbine blade samples is exposed under geothermal steam for 5 months. Then, almost no silica accumulation occurs on DLC even no-coated blade get certain amount of silica accumulation. As a result of above, we believe that DLC is new solution can solve silica accumulation troubles generally happens in geothermal power generation systems.

Surface Engineering - Applied Research and Industrial Applications
Room Palm 1-2 - Session IA3-ThM

Innovative Surface Engineering for Advanced Cutting and Forming Tool Applications

Moderators: Markus Esselbach, Oerlikon Balzer, Liechtenstein, **Fan-Yi Ouyang**, National Tsing Hua University, Taiwan

8:00am **IA3-ThM-1 Tool–Embedded Piezoresistive Thin–Film Sensors for Guide–Pad Normal Force Measurement in Deep Hole Drilling***, **Martin Rekowski [martin.rekowski@ist.fraunhofer.de]**,* Fraunhofer IST, Germany*; Lucas Brause, Sebastian Michel,* TU Dortmund University ISF, Germany*; Anna Schott, Christoph Herrmann,* Fraunhofer IST, Germany*; Dirk Biermann,* TU Dortmund University ISF, Germany

Deep hole drilling is essential for producing long, high-quality bores in safety–critical components such as hydraulic cylinders, turbine shafts, and fuel injectors. Its asymmetrical tool design and guide pad support enable excellent straightness and surface finish, but the contact zone experiences severe thermo–mechanical loads and steep temperature gradients followed by rapid oil quenching. These conditions can induce residual stresses and micro-structural alterations (e.g., white etching layers), directly affecting surface integrity and fatigue performance. Because the contact zone is inaccessible, workpiece-side measurements are limited and often require post-process analysis. Miniaturized thin-film sensors integrated directly into the tool's guide pad offer a robust and space-saving way to measure temperature, normal force, and wear in the force flow in real time. This paper details the design, fabrication, and characterization of a tool–embedded piezoresistive thin–film sensor system for measuring guide pad normal force with integrated temperature compensation. A 6 µm hydrogenated carbon DiaForce® (DLC) layer is deposited on a polished and hardened high-speed steel substrate (Rz = 0.1 µm) using plasma enhanced chemical vapor deposition (PECVD) process. Electrodes and conductive tracks are applied in a 0.2 µm thick chromium layer, which is deposited using physical vapor deposition (PVD) and patterned with photolithography and wet chemical etching. The stack is insulated and protected with SICON® layers. Three sensor structures (F1–F3) are positioned in the force flow to resolve normal loads, while additional unloaded DiaForce® electrodes act as temperature references to decouple thermoresistive drift from the force signals. Two overlapping thin steel washers (t = 150 µm) ensure uniform electrode loading. The overlap and thus the area of the loaded surface was determined in preliminary tests and can be adapted to the respective measurement conditions. Shielded leads were soldered to the base body and provide connectivity to a telemetry system. Calibration is done by recording resistance changes versus temperature and pressure. The DiaForce® reference electrodes show a decreasing exponential temperature dependency modeled by the Steinhart–Hart equation, enabling real–time compensation of the force signal, while pressure sensitivity is linear to quadratic over the investigated range. Servo–press experiments confirm stable signal deflection under combined mechanical loading and dynamic thermal transients. The thin-film sensor system is applied to both single–lip drilling (SLD) and BTA deep hole drilling

8:20am **IA3-ThM-2 Novel High-Power Pulsed "Bipolar" Dual-Magnetron Sputtering Technology Using Cylindrical Cathodes for Deposition of Advanced Coating in Industrial Applications***, **Daniel Karpinski [d.karpinski@platit.com]**, Guillaume Wahli, Christian Krieg, Pavla Karvankova,* PLATIT AG, Switzerland*; Jan Kluson,* PLATIT a.s., Czechia*; Hamid Bolvardi, Andreas Lümkemann,* PLATIT AG, Switzerland

The automotive industry faces major challenges amid the shift from combustion engines to electromobility. Customers now demand higher productivity through shorter coating cycles and increased machining speeds for difficult-to-machine ferrous and non-ferrous alloys. These trends require advanced coatings.

Cathode Arc Evaporation (CAE) is widely used in the tooling industry, as it produces coatings with high density, hardness, and deposition rate. However, it generates macroparticles that increases surface roughness. In contrast, HiPIMS can achieve comparable coating properties with significantly lower roughness, albeit at a reduced deposition rate. Surface quality may deteriorate due to micro-arcing and discharge instability when less conductive nitride compound form on the target. To reduces micro-arcing and enhances coating density and hardness, bipolar-HiPIMS was developed, introducing a positive pulse immediately after the negative one to discharge target and accelerate positive ions toward the substrate. Nevertheless, the anode disappearance when depositing low-conductive coatings has not been solved.

This contribution presents PLATIT's recently developed TRM® (Twin Rotating Magnetron) technology installed in the Pi111 coater. The TRM® consists of dual rotating cylindrical magnetron with a Closed Unbalanced Magnetic Field (CUMF), powered by Bi-Pulse HiPIMS operated in asymmetric mode. In this mode, one magnetron operates at high power (up to 13 kW) while the other serves as a low power (0.5 kW) self-cleaning anode. The TRM® operates in "bipolar" mode where each magnetron alternates its polarities, each sequentially acts as a cathode and as a positively biased anode (since the anode is not grounded) during consecutive half-cycles of the pulse period. Owing to the combined effect of high average target power density, the CUMF, and the dense Me^+ plasma generated during short HiPIMS pulses, the TRM® process achieves a high Ion Current Density to the Substrate (ICDS). The high ICDS, together with process stability and high target power density, are important factors for fast deposition of high-performance coating without the need for high substrate bias. To evaluate the coating performance between CAE and TRM®, AlTiN, AlCrN and TiSiN coatings were sputter-deposited from alloy cylindrical targets in an $Ar+N_2$ atmosphere. Coating growth was controlled by synchronized pulse substrate biasing, selectively utilizing the Me^+ rich portion of the sputtered flux. To evaluate the coating performance, the following tests were conducted: adhesion, structure and microstructure (TEM), nanoindentation, and cutting tests (side milling and micro milling).

8:40am **IA3-ThM-3 Development of in-Situ Cleaning Processes and Customized Coatings on Numismatic Coinage Dies for Minting Industry***, **João Coroa [joao.coroa@teercoatings.co.uk]**, Alexander Gorupp, Parnia Navabpour, Giuseppe Sanzone, Hailin Sun,* Teer Coatings, UK **INVITED**

The minting industry is responsible for the design, production, and distribution of coins and medals both for national currencies and for commemorative purposes. The design and fabrication of coin dies combine expert craftsmanship with state-of-the-art technology which preserves value and celebrates heritage by producing coins of beauty and enduring worth.

The coin dies typically comprise of both highly-polished and frosted areas to create distinct visual contrasts and intricate images. The surface of dies needs to be coated with hard, wear resistant coatings for the die to withstand the force and repeated impact exerted on it during coin production. Physical vapour deposition (PVD) is an environmentally-friendly method used for the deposition of coatings on dies. Some of the processes, such as laser engraving, used in the minting industry during the production of dies have created new challenges for the PVD coatings.

Currently, Teer coatings PVD systems used in the minting Industry are capable of producing coatings for numismatic, proof or circulation coin dies using the PVD magnetron sputtering technique. To overcome the new challenges, an in-situ linear ion source device has been integrated in the coating equipment. It generates a wide, collimated plasma beam for treating large substrates. It is used to pre-clean surfaces by removing the surface oxides and hydrocarbons in order to improve the adhesion of the deposited thin films. At the same time, the process is tailored to ensure that the original features such as roughness, etc. are retained.

This study presents some of the developments which achieve the industrial demands, both through optimised coating design, and through equipment developments that enable the combination of different treatment and deposition technologies to improve the coating performance.

9:20am **IA3-ThM-5 Machining of Hardened Steels under Dry Conditions: Wear Mechanisms of AlTiSiN and AlTiXN-TiSiZN (X, Z= nonmetal elements) Coatings***, **Rong Zhao [rong.zhao@eifeler-vacotec.com]**, Simon Evertz, Alexander Fehr, Markus Schenkel,* voestalpine eifeler Vacotec GmbH, Germany

To obtain more environmentally friendly and cost efficient production processes, lubricants in milling applications are either removed completely or reduced to a minimum. Thereby, protective coatings for tools gain even more importance. Dry machining of hardened steels presents significant challenges due to elevated temperatures and the simultaneous occurrence of abrasive and adhesive wear. AlTiSiN based coating systems have been the state of the art for milling applications under these demanding conditions. In this study, milling tests were conducted to evaluate the performance of milling tools with different coatings. The coated tools exhibited varying degrees of wear and service life. Hence, understanding the underlying wear mechanisms is decisive for the development and selection of next-generation coatings, as wear is closely linked to tool longevity. Two types of coating systems were investigated: one AlTiSiN coating and one AlTiXN-TiSiZN coating. Wear was analyzed using confocal microscopy, scanning electron microscopy (SEM), and energy dispersive X-ray spectroscopy. Distinct wear patterns and mechanisms were identified for each of the coatings. The results demonstrate that the AlTiXN-TiSiZN coating exhibits superior wear resistance, which makes it particularly suitable for milling of hardened steels with a hardness higher than 55 HRC.

10:20am **IA3-ThM-8 Laser Texturing and DLC Optimization for Tribological Performance Improvement***, **Mirko Zago [mirko.zago@argor-aljba.com]**,* Argor-Aljba, Switzerland **INVITED**

The combination of laser surface texturing and diamond-like carbon (DLC) coatings represents a promising strategy to achieve superior tribological performance in demanding mechanical applications. In this work, the influence of controlled micro- and nano-scale surface patterns generated by laser texturing on the adhesion, morphology, and stress distribution of optimized DLC films was systematically investigated. Different laser parameters were tuned to tailor dimple density, depth, and distribution, enabling improved lubricant retention and reduced real contact area. Parallel optimization of the DLC deposition process (Dialong VS Dropless Argor Aljba Technologies) focused on intrinsic film properties such as macroparticles distribution, hardness, elastic modulus, residual stress, and sp^2/sp^3 bonding ratio. Tribological tests under dry and lubricated conditions demonstrated that the synergistic effect of surface texturing and DLC optimization leads to a substantial reduction in friction coefficient, enhanced wear resistance, and increased load-bearing capacity compared to conventional coatings. These results highlight the potential of integrating laser surface engineering with advanced carbon coatings as a robust pathway for the design of high-performance components in automotive, aerospace, and precision mechanics industries.

11:00am **IA3-ThM-10 Over 30 Years of PVD Aluminium-Oxide Based Hard Coatings in Demanding Industrial Applications***, **Philipp Immich [pimmich@hauzer.nl]**, Louis Tegelaers, Julia Janowitz, Daniel Barnholt,* IHI Hauzer Techno Coating B.V., Netherlands*; Rolf Schäfer, Tobias Radny,* Robeko GmbH & Co. KG, Germany*; Thomas Schütte,* PLASUS GmbH, Germany

Over the past six decades, the requirements for hard coatings in protective applications have increased significantly. The progression from simple TiC monolayer coatings deposited via Chemical Vapor Deposition (CVD) in the 1960s to today's sophisticated multilayer systems has been driven by several key factors: enhanced reliability of industrial coating equipment, continuous optimization of substrate materials and new pre- and post-treatment processes.

Among the most notable advancements are aluminium oxide (Al_2O_3) coatings, which have become a benchmark in modern cutting applications. Their unique phase structures offer performance benefits that are difficult to replicate with other coating systems. Alumina's high hardness, electrical insulation, chemical inertness, and thermal stability make it exceptionally well-suited for demanding environments.

Beyond cutting tools, aluminium oxide is widely used across various industrial sectors. Its mechanical strength and thermal resilience support its role in protective coatings, while its excellent insulating properties are essential for sensor technologies. Additionally, its optical transparency and chemical resistance make it ideal for advanced protective layers.

In cutting tool applications, CVD remains the established method for depositing aluminium oxide. However, over the past 30 years, Physical Vapor Deposition (PVD) has gained increasing relevance, because of the lower deposition temperatures compared to CVD —initially driven by high-temperature cutting applications and more recently expanding into low-temperature applications such as insulating coatings for sensors.

Despite its versatility, scaling the PVD deposition of alumina thin films for industrial use presents several challenges. RF sputtering from compound targets can produce stoichiometric, high-quality coatings, but its low deposition rate limits its practicality for mass production. PVD techniques—particularly dual magnetron sputtering (DMS) from metallic targets—offer significantly higher deposition rates and effectively address issues such as the disappearing anode.

In this presentation, we will highlight ongoing developments in PVD oxide coatings—including innovations in coating equipment and advanced deposition technologies—that are opening new possibilities for enhanced cutting performance and broader industrial applications. We will compare various regulation strategies, examine the properties of alumina films deposited at different temperatures, and discuss future technological improvements that could further optimize deposition processes.

11:20am **IA3-ThM-11 Sputtered CrN-based coating concepts for plastic injection molding***, **Alexander Fehr [alexander.fehr@eifeler-vacotec.com]**,* Voestalpine eifeler Vacotec, Germany

Typical demands in plastic processing are minimized material adhesions, better deformability as well as a certain gloss level of the produced plastic parts. Therefore, surfaces in plastic processing often require mirror-like polishing to produce very smooth plastic parts. Furthermore, there is a challenge with very complex structured plastic molds when it comes to the reproduction of textures on the plastic part. These applications do not only require a wear resistant but also a near net shape surface solution to guarantee a conservation of the gloss level as well as a persistent surface quality of the produced plastic parts. Since plastic injection mold steels typically have a low annealing temperature, a sputtered, low-temperature coating represents a well-suited approach. In this context, the CHROME-X coating solution from voestalpine eifeler Vacotec will be presented with regard on the application on textured surfaces. It will be shown why a sputtered Cr based coating delivers more advantages for PIM applications when compared to an arc Cr based film. Furthermore, the influence of the sputtered coating on the gloss level of the plastic part will be addressed.

11:40am **IA3-ThM-12 Study on Multilayer Thick ta-C Coating Process on Cutting Tools for CFRP Machining Using Filtered Cathodic Vacuum Arc Deposition***, **Jongkuk Kim [kjongk@kims.re.kr]**, Jae-Il Kim, Young-Jun Jang,* Korea Institute of Materials Science, Republic of Korea

Carbon fiber reinforced plastic (CFRP) is a composite material consisting of a polymer matrix and carbon fibers, which requires excellent mold release, low friction, and high wear resistance during cutting. To meet these demands, cutting tools are often coated with high-hardness carbon-based films. Among these, tetrahedral amorphous carbon (ta-C) coatings exhibit outstanding hardness and low friction while minimizing chipping and substrate damage due to their nanolayer structure. However, the high intrinsic stress of ta-C limits its achievable thickness, hindering its application as a thick, durable coating.

In this study, a filtered cathodic vacuum arc (FCVA) system was employed to deposit thick ta-C coatings (>2.5 μm) on cutting tools. The effects of substrate bias voltage and process temperature on internal stress were investigated through multilayer film design. The deposition system consisted of an anode-layer ion source, a magnetron sputtering source, and a 90°-bent magnetic FCVA source. Stainless steel strips (100 μm) were used for stress analysis, and WC–Co inserts (15 × 15 mm) were used as substrates.

Prior to deposition, the substrate surface was cleaned using Ar ion etching at 2.5 kV and 400 mA, followed by deposition of a 500 nm Ti buffer layer via magnetron sputtering (6 A). The ta-C films were deposited using the FCVA source with alternating high-hardness (–70 V) and low-hardness (–200 to –500 V) layers, each 250 nm thick, yielding a total thickness of 2.5 μm. Additionally, the low-hardness layer (–500 V) was fixed at 100 nm, while the ratio between high- and low-hardness layers (1:2, 1:3, 1:4) was varied to optimize stress control.

The optimized multilayer structure (–500 V/–70 V, 1:3 ratio) produced a 63 GPa hardness and 4.5 GPa residual stress, enabling stable and uniform deposition even on the cutting edge of the inserts. These results demonstrate that proper stress control through multilayer engineering allows the formation of thick, high-hardness ta-C coatings suitable for CFRP machining applications, offering a promising route to improve tool performance and durability.

Keywords:

ta-C (tetrahedral amorphous carbon); Filtered Cathodic Vacuum Arc (FCVA); Cutting Tool; Hardness; DLC (Diamond-Like Carbon); Wear Resistance

12:00pm **IA3-ThM-13 Enhanced Fe and Ni bonded NbC Laser Surface Engineered Hardmetals: Alternative Cutter Materials for Electric Vehicle Applications***, **Rodney Genga [RODNEY.GENGA@WITS.AC.ZA]**,* University of the Witwatersrand, South Africa*; Suzan Conze, Lutz-Michael Berger, Johanes Pötschke,* IKTS Fraunhofer Institute, Germany*; Julien Witte, Dirk Schroepfer,* BAM Berlin, Germany*; Adam Čermák, Pavel Zeman,* Czech Technical University in Prague, Czech Republic*; Sinoyolo Ngongo, Arno Janse van Vuuren,* Nelson Mandela University, South Africa

The substitution of tungsten carbide (WC) and cobalt (Co) in hardmetals has gained increased attention in recent years due to the reclassification of Co as a carcinogenic substance and the designation of both Co and W as critical raw materials by the European Union and under the U.S. National Toxicology Program. Thus, this study investigates the development and performance of advanced NbC-based hardmetals utilizing nickel (Ni) and iron (Fe)-based binders as sustainable alternatives for metal machining applications within the electric vehicle (EV) manufacturing sector.

The materials were developed using a Machining Property Led Tailored Design (MPLTD) approach, a reverse engineering strategy that leverages machining performance data to guide the optimization of microstructural, mechanical, and tribological properties. Four novel NbC-based hardmetals were synthesized, two with Ni-based binders and two with Fe-based binders. These were benchmarked against two reference materials: a standard WC-Co composition and a conventional NbC-12Ni grade. Comprehensive material characterization was conducted using field emission scanning electron microscopy (FE-SEM), annular dark-field scanning transmission electron microscopy (ADF-STEM), Vickers hardness testing, fracture toughness measurements, and elastic modulus evaluations.

Cutting tool inserts were manufactured from these hardmetals were further enhanced via femto-second laser surface engineering (Fs-LSE), which was employed to form laser induced chip breakers and modify cutting edge morphology. The microstructural effects of Fs-LSE were examined through ADF-STEM and selected area electron diffraction (SAED) analyses. The performance of both untreated (blank) and Fs-LSE-modified inserts was evaluated through interrupted face milling tests on AZ31 automotive grade magnesium alloy. As AZ31 is considerably lighter than both steel and aluminum, its use in EV components significantly improves power-to-weight ratios and operational efficiency. The laser enhanced Fe- and Ni-bonded NbC inserts demonstrated machining performance comparable to industrial WC-Co benchmark grades. Furthermore, the Fs-LSE process resulted in over 100% reductions in flank wear and up to 80% decreases in resultant cutting forces. The inserts' performance in this study provided valuable insights into the suitability of alternatives to WC and Fs-LSM for automotive industrial applications

Surface Engineering - Applied Research and Industrial Applications
Room Town & Country D - Session IA2-2-ThA
Surface Modification of Components in Automotive, Aerospace and Manufacturing Applications II
Moderators: Miha Cekada, Jozef Stefan Institute, Slovakia, **Satish Dixit**, Plasma Technology Inc., USA

1:40pm **IA2-2-ThA-2 From Development to Series Production in Automotive – The Role of Coating Characterization***, **Nazlim Bagcivan [nazlim.bagcivan@schaeffler.com]**,* Schaeffler Technologies GmbH & Co. KG, Germany **INVITED**

Coatings have contributed significantly to performance improvements in automotive applications in various ways, such as friction reduction, extended service life through wear protection, and increased corrosion resistance. Meeting specified properties plays a central role in achieving these goals.

The verification of these properties and the characterization process differ greatly between research and development (R&D) and industrialization. While R&D focuses on the pure verification of achieving the specified property, industrialization and subsequent series production aim to ensure that these properties are reliably achieved through robust coating processes while maintaining quality characteristics.

This presentation highlights the role of coating property characterization in both R&D and industrialization. It presents and discusses both commonalities and differences. The goal is not only to illustrate selected characterization methods with examples but also to provide insight into methodological approaches, such as the Production Part Approval Process (PPAP) or the determination of process capability.

2:20pm **IA2-2-ThA-4 Investigation of Salt Solution Drying Behavior to Improve Coating Performance for Marine Turbomachinery***, **Sadikshya Pandey [pande224@umn.edu]**,* University of Minnesota, USA

Salt deposition and fouling in compressors contributes to performance degradation of gas turbines operating in marine environments. These deposits accumulate over time as seawater mist enters with the intake air and evaporates during operation. Developing effective coating strategies that limit salt accumulation is essential to improve operational reliability. Although antifouling coatings are proposed for such applications, the mechanisms linking surface properties to salt deposition behavior are not well understood. In this study, we performed salt solution misting experiments on substrates with distinct surface chemistries to investigate how the surface properties influence salt deposition dynamics. Observations from these experiments reveal key relationships between wetting, drying conditions, and deposition patterns. These insights provide a foundation for the rational design of engineered coatings with enhanced antifouling performance, aimed at reducing salt-induced performance losses in marine turbomachinery.

2:40pm **IA2-2-ThA-5 Enhancing Mechanisms for the Increased Performance of Nuclear Energy and Aerospace Coating- and Solid-RHEA Components***, **Sal Rodriguez [tayloreddydk1@gmail.com]**,* 11251 Pino Ave. NE, USA*; Satish Dixit,* Plasma Technology Inc., USA*; Nima Fathi,* Texas A&M University, USA **INVITED**

Refractory high-entropy alloys (RHEAs) are composed of multi-principal elements typically having near-equiatomic proportions. RHEAs are formed from refractory elements such as Nb, Ta, Mo, W, Hf, and Zr, which offer outstanding mechanical strength at elevated temperature, corrosion resistance, irradiation tolerance, and thermal stability. Hence, this provides a materials class ideal for harsh-environment applications often encountered in aerospace and nuclear energy applications. For example, NbTaTiV offers an exceptional 23% strain-to-failure and yield strength in excess of 1,300 MPa at room temperature, while some RHEAs have reached a yield strength of 375 MPa at 1,873 °C. Moreover, an alloy has good machinability performance if its engineering strain is greater than 5% at room temperature, which NbTaTiV far exceeds.

We present examples design, synthesis, and performance, with emphasis on thermal spray coatings based on high velocity oxygen fuel, advanced atmospheric plasma spray, high velocity air fuel, and cold spray suitable for RHEAs. In addition, we demonstrate the advanced manufacturing of industry-grade solid (bulk) RHEA components via spark plasma sintering (SPS) and subsequently machined to net shape via computer numerical control (CNC).

We investigate key properties of the RHEA coatings and solids, including hardness, modulus, ductility, machinability, wear resistance, and friction, as well as corrosion- and radiation-resistance behavior. But most importantly, we show leading-edge examples of industrial-grade RHEA and refractory-element based coated components, including turbine diffusers. Moreover, the CNC of a 3.5 kg solid NbTaTiV RHEA generated a 140-mm turbine diffuser, a 0.5-mm thick turbine blade, and small plates with flow channels for compact heat exchangers, all without visible microcracks at 30X magnification—a world's first. Case studies for NbTaTiV and other RHEAs demonstrate exceptional ductility, machinability, and protective performance when applied as coatings on stainless steels and Inconels under molten-salt and high-temperature environments.

These advances corroborate RHEAs as transformative materials for key industries, including energy, aerospace, electronics, and defense. As a result of their high-strength, high-temperature, and harsh-environment survivability, some applications include advanced nuclear reactors, plasma facing fusion components, compact heat exchangers, high-temperature jet turbines, hypersonics, quantum computer hardware, radiation-resistant electronics, high-temperature combustion, concentrated solar, missile defense, and biomedical devices.

3:20pm **IA2-2-ThA-7 Element-Resolved Investigation of Zr-Based Conversion Coatings on Aluminum and Zinc Alloy Substrates by AESEC and GD-OES***, **Suyeon Lee [suyeon.lee@horiba.com]**, Alice Stankova, Patrick Chapon,* HORIBA Europe Research Center, France*; Kayvon Savadkouei,* HORIBA, USA*; Junsoo Han,* Sorbonne University, France*; Dominique Thierry, Dan Persson,* Research Institutes of Sweden*; Kevin Ogle, Borhan Sultan,* Chimie Paris Tech, France

Zirconium-based conversion coatings (ZCC) have been considered in the last decades as environmentally friendly alternatives to chromate systems and are widely used in applications of corrosion protection of alloys.

Here, the formation and growth mechanisms of ZCC were investigated on two distinct alloy systems which are aluminum and zinc alloys using a combination of atomic emission spectroelectrochemistry (AESEC) and glow discharge optical emission spectroscopy (GD-OES).

For zinc-based alloy coatings, the effects of Cu(II) and NO_3^- additives in a Zr conversion coating bath (based on H_2ZrF_6) were investigated. Cu(II) ions underwent a displacement to form Cu(0) which acted as local micro-cathodes. In parallel, this accelerated NO_3^- reduction and hydroxide generation, thereby enhancing ZrO_2 film (i.e., ZCC) formation. The interplay between alloying elements in the presence/absence of additives was monitored in real-time by AESEC. The synergy between Cu(II) and NO_3^- resulted in the highest Zr incorporation in the coating, as confirmed by GD-OES depth profiling.[1]

For aluminum alloys, the influence of acid pickling pretreatment and bath additives (F^-, NO_3^-) on the dissolution kinetics of alloying elements and subsequent Zr deposition was quantitatively resolved by combining *in situ* AESEC and *ex situ* GD-OES. The results showed that nitro-sulfuro-ferric pickling homogenized surface reactivity and promoted the congruent dissolution of Al and Mg during subsequent exposure to the ZCC bath, leading to more uniform ZCC films.[2]

By correlating *in situ* elemental dissolution kinetics (AESEC) with *ex situ* depth-resolved composition (GD-OES), this comparative study demonstrates how to govern the balance between dissolution and precipitation in ZCC processes. The combination of two techniques provides a quantitative solution for optimizing Cr-free conversion coatings across different alloy systems.

[1] J. Han, D. Thierry, K. Ogle, Surface and Coatings Technology,402, 126236, 2020.

[2] B.B.M. Sultan, D. Persson, D. Thierry, J. Han, K. Ogle, Electrochimica Acta, 503, 144820, 2024.

4:00pm **IA2-2-ThA-9 Inner Diameter Coatings – a New Dimension in PVD Applications***, Martin Jaroš, **Bernhard Kohlhauser [bernhard.kohlhauser@plasmateria.com]**,* Plasmateria GmbH, Austria **INVITED**

Industrial machine components such as pipes, barrels, and cylinders are in great need of enhanced surface properties by protective coatings. These coatings are required to increase oxidation-, corrosion-, and wear resistance. Due to geometrical difficulties the standard commercially relevant PVD technologies are not suitable for such types of applications.As a result, the standard market solution has been chrome plating for many decades. Unfortunately, this method poses severe health risks to workers and is environmentally extremely problematic due to use of carcinogenic hexavalent Chromic acid/ Chrome (VI) oxide as source for the Cr coating.

The surface technology industry tried to find a suitable replacement for inner surface of components fordecades, unsuccessfully – until now. Plasmateria's Chrome coating solution offers a ecofriendly alternative to hard chrome plating of internal surfaces. Plasmateria's PVD-based technology is the ideal hard chrome replacement for inner diameters of automotive, aerospace, defence and machine components. Furthermore, it is possible to achieve additional surface protection by applying advanced ceramic coatings. With an improved corrosion resistance, hardness and thermal stability transition metal nitrides are the ideal coating for forming tools and inner surfaces under serve mechanical or chemical strain.

The properties of Inner Diameter Coatings by PVD, such as hardness, microstructure, adhesion and corrosion resistance of the created Cr and/or CrN films are discussed in detail. The deposition capability is being demonstrated on selected examples of (i) small inner diameter components of approx. 6 mm (with up to the 100 times of their length) and (ii) large inner diameters components of approx. 30 - 50 mm.

4:40pm **IA2-2-ThA-11 Solid Particle Erosion Mechanisms of Organic Matrix Composites With and Without Protective Coatings***, **Veronika Simova [veronika.simova@polymtl.ca]**, Etienne Bousser,* Polytechnique Montréal, Canada*; Marjorie Cavarroc,* Safran Tech, France*; Juan Manuel Mendez,* MDS Coating Technologies, Canada*; Ludvik Martinu, Jolanta Ewa Klemberg-Sapieha,* Polytechnique Montréal, Canada

Organic matrix composites (OMCs), such as carbon fibre–reinforced polymers (CFRPs), have become widely used in the aerospace industry due to their low density, excellent strength-to-weight ratio, stiffness, aerodynamic smoothness, and resistance to fatigue and corrosion. In modern aircraft design, composite materials are employed extensively in both primary and secondary structures to reduce savings and improve fuel efficiency. In engines, they are mainly used in the cold section, such as the fan blades, fan cases, nacelles, and acoustic liners.

When subjected to solid particle erosion (SPE), CFRPs exhibit wear rates more than an order of magnitude higher than those of metallic materials. As any aircraft surface can be exposed to SPE, understanding the erosion mechanisms is crucial.

The erosion behavior of an uncoated OMC, consisting of carbon fibers (CF) embedded in an epoxy matrix (EP), was first examined by evaluating the effects of the erodent particle type, size and velocity, impingement angle, and CF orientation. Erosion rates were determined based on volume losses measured by optical profilometry, with SEM used to understand the failure mechanisms. It has been found that the SPE of the CFRPs arises from two competing erosion mechanisms: brittle erosion of the fiber, and ductile-like wear of the epoxy matrix. Composites with fibers oriented parallel to the erosion direction showed lower erosion rates than those with fibers oriented perpendicularly, especially at low impingement angles (30°).

Given that the erosion rates of uncoated OMCs are significantly higher compared to traditional metal materials, applying erosion resistant coatings is essential to enhance their lifetime and enable their extensive use in aerospace applications.

Therefore, protective TiAl and TiAlN coatings were deposited by pulsed DC magnetron sputtering from a rotating cylindrical TiAl target, in low (9.1%) or high (91%) duty cycle modes. Prior to deposition, short plasma etching was performed to activate the surface and promote the coating adhesion on the OMC substrate. The use of a cylindrical target, which enables high deposition rates, allowed for the preparation of thick coatings (up to 50 μm), with low substrate heating (~100°C) and RF biasing (−100 V). Erosion testing was performed with 50μm Al_2O_3 particles at angles of 30° and 90°, and the results were compared with uncoated OMCs. The 50μm-thick TiAl coating enhances the erosion resistance of OMCs at 75 m/s and 90° up to a factor of 6, providing a solid foundation for further optimization of coating properties, adhesion, and thickness to achieve even greater improvements in the erosion performance of OMCs.

Surface Engineering - Applied Research and Industrial Applications
Room Golden State Ballroom - Session IA-ThP

Surface Engineering – Applied Research and Industrial Applications Poster Session

IA-ThP-1 Corrosion Resistance of CrN, AlCrN and TiAlN deposited on Waspalloy, *Giovany Biava, Gelson Biscaia de Souza,* State University of Ponta Grossa, Brazil*; Irene Bida de Araujo Fernandes Siqueira,* Instituto Lactec, Brazil*; Rodolpho Fernando Vaz,* University of Barcelona, Spain*; **ANDERSON Geraldo Marenda PUKASIEWICZ [anderson@utfpr.edu.br]**,* Federal University of Technology Paraná, Brazil

Corrosion problems in many components used in oil refineries are subject to corrosion issues. The cause of failure for these parts is primarily due to material degradation, as they are inserted into a corrosive atmosphere with significant sulfur concentrations and other oxidizing agents. Several types of coatings are reported in the literature that are feasible under the equipment's conditions, aiming to mitigate the effects of corrosion at both high and room temperatures. Thus, the present study aimed to evaluate the behavior of thin coatings deposited by the physical vapor deposition (PVD) technique against corrosion phenomena at room temperatures, as a component in aggressive environments where they are applied. To understand the behavior of the Waspaloy alloy and PVD coatings against corrosion at room temperature, an electrochemical corrosion test was performed according to ASTM G59 and G102. Surface analysis of the CrN, AlCrN, and TiAlN coatings revealed the presence of some protuberance-like particles and pores, which are closely related to the processing parameters of the PVD coatings. Based on microscopy of the coatings' surfaces, it is clear that the presence of defects in the CrN coatings is significantly lower than in the AlCrN and TiAlN coatings. Visual observations using SEM analysis of the coatings indicate, in all cases, a smooth and dense surface with few pores and particle inclusions. The average thickness of the CrN coating is approximately 2.77 µm, the AlCrN coating is approximately 3.5 µm, and the TiAlN coating is approximately 6.0 µm. The OCP values for all three PVD coatings studied are higher than those for the Waspaloy superalloy. This indicates that a protective film is easily built on the surface of the coated samples in aggressive environments; or that the components that make up the coating are chemically more stable in aggressive environments than the Waspaloy base metal. The lower OCP value for TiAlN, in relation to the other coatings, indicates that this coating is more susceptible to corrosion than the others, and is also related to the greater number of defects and porosity. Based on the Ecorr and icorr values, it can be seen that the corrosion resistance of AlCrN is better than that of TiAlN and CrN coatings. This is due to the ability of AlCrN coatings to form a passive layer on the surface. The addition of a third element (such as Al) to transition metal nitrides improves corrosion resistance. During corrosion, Al readily forms an Al2O3 layer on the coating surface, which passivates the surface and prevents further corrosion attacks.

IA-ThP-2 Interface-Engineered Grain Boundary Diffusion for Enhanced Coercivity, Corrosion Resistance, and Thermal Stability in Thick NdFeB Magnets with Efficient Rare-Earth Utilization, ***Ching-Chien Huang [huangcc@nkust.edu.tw]**,* National Kaohsiung University of Science and Technology, Taiwan

Grain boundary diffusion (GBD) has emerged as a powerful interface engineering strategy to enhance the magnetic performance and environmental durability of sintered NdFeB magnets. This study presents a single-stage GBD process utilizing dysprosium (Dy) vapor adsorption, followed by subsequent aging treatment, to overcome coercivity degradation and thermal instability in thick-section magnets. By precisely controlling the diffusion temperature between 940 and 950 °C and the duration from 8 to 16 hours, significant improvements in intrinsic coercivity ($_iH_c$) were achieved. For samples with thicknesses of 5.5 mm and 6.5 mm, $_iH_c$ increased to 25.78 kOe and 25.06 kOe, corresponding to enhancements of 34.06 % and 30.32 %, respectively. These improvements enabled a magnetic grade transition from N44H to G42UH without compromising remanence (B_r) or maximum energy product ($(BH)_{max}$). Microstructural analysis using glow discharge optical emission spectroscopy (GDOES) and field-emission electron probe microanalysis (EPMA) confirmed uniform Dy enrichment at grain boundaries and the formation of thermally stable $(Nd,Dy)_2Fe_{14}B$ intergranular phases, supporting deep and homogeneous diffusion. Electrochemical evaluation via Tafel polarization revealed substantial reductions in corrosion current density and increased polarization resistance, indicating enhanced grain boundary chemical stability. The proposed method enables simultaneous enhancement of coercivity, thermal stability, and corrosion resistance. This interface-focused strategy provides a scalable and resource-efficient solution for fabricating high-performance NdFeB magnets for electric vehicles, offshore wind turbines, and aerospace applications.

Surface Engineering - Applied Research and Industrial Applications
Room Town & Country D - Session IA1-FrM
Advances in Application Driven Research and Hybrid Systems, Processes, and Coatings

Moderators: Hana Barankova, Uppsala University, Sweden, **Ladislav Bardos**, Uppsala University, Sweden, **Vikram Bedekar**, Timken Company, USA

8:00am **IA1-FrM-1 Hybrid Sealing Post-Treatments for Plasma Electrolytic Oxidation Coatings***, **Beatriz Mingo [beatriz.mingo@manchester.ac.uk]**,* The Univeristy of Manchester, UK

Plasma Electrolytic Oxidation (PEO) is an increasingly popular surface modification technique used as an environmentally friendly alternative to conventional anodizing treatments. PEO coatings usually present a layered morphology, formed by a compact inner layer and an outer layer with variable porosity. Over extended periods of exposure, aggressive electrolytes penetrate through the porosity compromising the barrier properties of the coating.

This study aims to address this issue by developing a novel hybrid post-treatment based on fibrous silica, which incorporates cerium as corrosion inhibitor. This treatment is applied using a hydrothermal technique to seal the coating's external porosity. The Ce-containing nanoparticles cover the material's surface, penetrating pores and defects and blocking potential entry points for the electrolyte. This significantly enhances the corrosion performance, improving it by up to two orders of magnitude. The synthesized materials are thoroughly characterized in terms of composition and morphology and their corrosion performance is evaluated using electrochemical techniques.

8:20am **IA1-FrM-2 Memristive Effects in PEO Alumina: Mechanisms and Technological Implications***, Aleksey Rogov, Allan Matthews, **Aleksey Yerokhin [Aleksey.Yerokhin@manchester.ac.uk]**,* University of Manchester, UK **INVITED**

Modern trends towards sustainable, resource- and energy efficient manufacturing bring surface engineering of light alloys at the forefront of research interest. Plasma Electrolytic Oxidation (PEO) attracts significant attention as an advanced technology platform for high-performance ceramic coatings on light alloys, which enables lightweighting of structural components, improved protection form wear and corrosion as well as development of new functional devices and consumer products. PEO is an electrochemical technique which utilises pulsed bipolar polarisation to grow anodic oxides above the potentials of dielectric breakdown. A large number of experimental variables and significant non-linearity provide major challenges for process optimisation, diagnostics and control, hindering its broader adoption in industry. We attempt to address these challenges by developing a mechanistic understanding of the behaviour of metal-oxide-electrolyte systems using original in-operando process diagnostic techniques. Recent studies of PEO treatments of Al indicate that this behaviour is influenced by dynamic rearrangements in the barrier layer of the anodic alumina grown under alternating cathodic and anodic polarisation. In contrast to common presentation of anodic oxides as dielectric barriers, the revealed dependence on polarisation history implies that such films should be treated as a memristive structures. This new understanding allows explaining unusual discharge behaviour observed during PEO treatments, including soft sparking transition and appearance of scanning waves propagating perpendicular to the direction of electric field. Although the barrier layer occupies a small portion of PEO coating located at the interface with the metal substrate, its evolution appears to influence both structural and morphological transformations in the whole coating. The presentation will therefore discuss the mechanisms underlying structural rearrangements in the barrier layer, their practical significance and implications for process energy efficiency and real-time control over coating characteristics and properties.

9:00am **IA1-FrM-4 Application-Driven Research in Surface Engineering for Advanced Cutting Tool and Component Applications - 25 years of cooperation between Plansee and Oerlikon** *-, **Peter Polcik [peter.polcik@plansee.com]**, Szilard Kolozsvari,* Plansee Composite Materials GmbH, Germany*; Denis Kurapov,* Oerlikon Surface Solutions AG, Liechtenstein*; Helmut Riedl, Paul Heinz Mayrhofer,* Institute of Materials Science and Technology, TU Wien, Austria **INVITED**

The persistent challenges in the field of PVD coatings—both in established and emerging applications—can be effectively addressed through close collaboration along the entire value chain. This paper highlights key milestones achieved through the long-standing partnership between Plansee Composite Materials and Oerlikon Surface Solutions, which has now spanned more than two decades. Substantial support from the Austrian Christian Doppler Research Association has enabled a strong collaboration between industry and a broad network of scientists from leading Austrian research institutions: Montanuniversität Leoben, the University of Innsbruck, and Technische Universität Wien.

Initiated in 2000, this collaboration was guided by clear objectives to advance the development of TiAl- and AlCr-based nitride coatings. Plansee contributed through innovations in target materials design, while Oerlikon provided the industrial platform for PVD coating processes. This paper provides an overview of systematic investigations on how variations in composition influence the properties of PVD-deposited thin films, ultimately leading to the industrial implementation of novel AlCrB- and AlCrSi-based hard coatings. These achievements were realized by establishing fundamental concepts, evaluating new coatings in both laboratory settings and industrial PVD systems, and consistently integrating findings into iterative development cycles.

To address new applications in machining, forming, and high-temperature environments, the research scope expanded beyond nitrides to include borides and carbides, with particular emphasis on enhancing oxidation resistance without compromising hardness.

The outcomes of this collaboration led to the development and successful market introduction of several coating solutions that contribute to a more sustainable and environmentally responsible economy.

9:40am **IA1-FrM-6 Cu Grain Engineering and Plating Process Reliability Study for Heterogeneous Integration***, **Shan-Yuan Wu [t113c77009@ntut.org.tw]**, Ying-Chao Hsu, Po-Chun Chen, Sheng-Ru Hsiao,* National Taipei University of Technology, Taiwan

The continuous improvement of integrated circuit (IC) performance is mainly driven by transistor scaling and advanced packaging technologies. In 3D heterogeneous integration with hybrid bonding and 2.5D interposers using through-silicon or through-glass vias (TSV/TGV), advanced packaging plays a vital role. Each application presents distinct reliability challenges: hybrid bonding requires strong adhesion at low temperatures, while TSV/TGV structures demand low stress and void-free filling. Ultra-fine-grained (UFG) copper addresses these issues by enhancing grain boundary diffusion and enabling low-temperature bonding, while its fine-grained structure promotes bottom-up via filling and suppresses seam voids during electroplating.

The formation of Ultra-fine-grained Cu is closely related to organic additives in the electrolyte, particularly polyethylene glycol (PEG) and bis-(sodium-sulfopropyl)-disulfide (SPS). In this study, various additive formulations were investigated under identical plating conditions. Electron backscatter diffraction (EBSD) results revealed that optimized additives reduced the average grain size from above 1 μm to 390 nm, demonstrating a strong correlation between additive control and microstructural refinement.

To elucidate the electrochemical influence of additives, linear sweep voltammetry (LSV) and electrochemical impedance spectroscopy (EIS) were performed using an Admiral Squidstat Plus potentiostat. The working electrode was a silicon wafer coated with a 100 nm PVD Cu seed layer.

The presence of PEG introduced a pronounced suppression effect due to the formation of a PEG–Cu–Cl adsorption layer on the cathode surface. In LSV, this suppressor layer increased the overpotential from 0.45V to 0.65V under the $100mA/cm^2$ current density, reducing the critical nucleus radius and promoting finer grain formation. This monolayer structure was further characterized by EIS, where the high-frequency semicircle in the Nyquist plots represented the impedance of the additive-adsorbed layer. Its gradual shrinkage during plating indicated additive depletion and a weakened suppression effect, while recovery after PEG replenishment reflected restored electrolyte stability. These findings provide a practical strategy for monitoring and maintaining plating bath quality through electrochemical analysis.

This study integrates EBSD and EIS to establish a quantitative and time-efficient framework for evaluating electrolyte stability and predicting Ultra-fine-grained Cu formation, offering valuable insights for optimizing copper electroplating reliability and grain size in advanced packaging processes.

10:20am **IA1-FrM-8 Advanced Coating Strategies to Combat Friction and Wear in Low-Viscosity Fuel Systems**, ***Eun Cairns* [Euan.Cairns@woodward.com]**, University of North Texas, USA; *Satish Dixit, S. Berkebile,* Plasma Technology Inc., USA; *Diana Berman, Samir M. Aouadi, Andrey A. Voevodin,* University of North Texas, USA **INVITED**

Fuel pump components operating with low-viscosity hydrocarbon fuels (< 3 cSt) experience high failure rates due to poor lubricity, leading to scuffing, seizure, and accelerated wear in boundary-lubricated metal contacts. Conventional steel surfaces, both uncoated and coated, are particularly vulnerable under these conditions. This work investigates advanced coating strategies to mitigate friction and wear in multi-fuel pump environments, focusing on hard wear-resistant coatings, soft solid lubricant films, and duplex systems.

A systematic evaluation of state-of-the-art industrial hard coatings was conducted using fuel surrogates (ethanol, decane, dodecane) and F-24 jet fuel. Several coatings demonstrated superior tribological performance, making them strong candidates for multi-fuel applications. In parallel, the potential of solid lubricant coatings, specifically MoS_2 deposited via spray techniques on steel and WC-17Co substrates, was explored. Tribological testing of solid lubricants in low-viscosity hydrocarbons was complemented by surface characterization using X-ray Photoelectron Spectroscopy (XPS), Raman spectroscopy, and Scanning Electron Microscopy (SEM). These analyses reveal how hydrocarbon properties, such as polarity, water affinity, chain length, viscosity, and contact angle affect chemical and structural changes in MoS_2, influencing micro- and nano-scale lubrication mechanisms. Additionally results show how duplex architectures, utilizing a hard, wear resistant underlayer, and a soft lubricious solid lubricant layer, are a step towards developing a more robust coating for low-viscosity fuel pump applications.

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