Surface Engineering - Applied Research and Industrial Applications
Room Town & Country D - Session IA2-1-MoA
Surface Modification of Components in Automotive, Aerospace and Manufacturing Applications I

Moderators: Dr. Satish Dixit, Plasma Technology Inc., USA, **Masaki Okude**, Mitsubishi Materials Corporation, Japan, **Dr. Jan-Ole Achenbach**, KCS Europe GmbH, Germany

1:40pm **IA2-1-MoA-1 Laser Surface Remelting Induced Reaction Sintering of Nickel and Titanium Powders***, Milton Lima [miltonsflima@gmail.com],* Institute for Advanced Studies, Brazil*; Alana Brito,* Technological Institute of Aeronautics, Brazil*; Felipe Costa,* BRENG Co., Brazil*; Rafael Siqueira,* Technological Institute of Aeronautics, Brazil*; Sheila Carvalho,* Federal University of Espirito Santo, Brazil

There is currently an interest in the synthesis and applications of mnemonic structure materials for various applications, such as biomedical, aerospace, automotive, and robotics. Shape memory alloys (SMAs) are metallic materials that can return to their initial state after being subjected to deformation as a result of increased temperature, increased pressure, or other stress conditions. These materials have been used in thermoelastic actuators in space applications, such as antenna supports and solar panel deployments, and can impact the manufacture of polymorphic aircraft engines and fuselages. SMAs, such as Nitinol (equimolar alloy of Ni and Ti), are difficult to fabricate, and the powder metallurgy route, whether classical or using laser powder bed fusion (L-PBF), has been constantly improved to meet new application niches. This study proposes reactive sintering of samples with equiatomic compositions of Ni and Ti to form Nitinol using laser surface remelting. Elementary powders were inserted into a high-energy ball mill to fabricate mechanically alloyed Ni-Ti powders, which were subsequently pressed in the form of discs (20 mm diameter, 5 mm thickness). An experimental arrangement with a vacuum chamber and fiber laser beam manipulation was developed to induce sufficient heat for the reaction of elementary powders. Spiral scanning of the fiber laser beam produced surface remelting that ignited the pressed powder mixture. Macro- and microstructural analyses, the crystalline structure, and the composition of the sample surface remelted with a beam power ranging from 10 to 46 W were performed. In this power range, the sintering time was varied between 55 and 295 s when the laser power was varied from 46 W to 10 W. Although the presence of intermetallic phases was approximately the same, the microstructure in the laser-surface-remelted region was more homogeneous than that in the sintered volume. At the end of sintering, tablets were obtained with an apparent density of 61%–67% and a large number of intermetallic phases, such as $NiTi_2$, Ni_3Ti, and Ni_4Ti_3, together with unreacted elemental powders (Ni and Ti). The samples prepared in air also presented these phases in addition to TiO_2 and NiTi. The air-processed samples presented an equimolar Nitinol phase, as observed by X-ray diffractometry. According to mass spectrometry analyses of secondary ions, the presence of air oxidized the surface of the grains, which reacted at shorter distances and generated the Nitinol phase.

2:00pm **IA2-1-MoA-2 A Comparative Study on the Formation of Micro-Arc Oxidation Coatings on AZ31 and AC84 Magnesium Alloys***, Chi-Hua Chiu [qiuqihua90@gmail.com], Shih-Yen Huang, Yueh-Lien Lee, Yu-Ren Chu,* National Taiwan University, Taiwan

Magnesium-aluminum-calcium (Mg−Al−Ca) alloys have attracted significant attention due to their excellent strength-to-weight ratio, good castability, and potential for flame retardancy, owing to the presence of calcium and aluminum. However, the applications of these alloys are limited by their poor corrosion resistance. Micro-arc oxidation (MAO) is one of the most common techniques for corrosion protection of magnesium alloys; however, the formation mechanism of MAO coatings is extremely complex and influenced by numerous process parameters, including the substrate effect. In this study, the mechanism of MAO coating formation on the AZ31 and dual-phase AC84 (Mg−8Al−4Ca) alloys was comparatively examined. The preliminary results reveal that, during MAO treatment at a constant anodizing voltage of 150V, unreacted Al_2Ca secondary phases were observed in the micro-arc oxidation coatings of AC84 magnesium alloys, causing non-uniform surface structures and thicknesses, which led to poor corrosion resistance compared to the MAO coating formed on AZ31.Conversely, AC84 exhibited better corrosion resistance than AZ31 when the voltage was increased to 250V. Further increasing the voltage to 300V resulted in the involvement of secondary phases in the reaction, leading to more uniform microstructures and chemical compositions of the coatings on both alloys. These findings suggest that the anodizing voltage plays a crucial role in the reaction behavior of secondary phases and the properties of the MAO coatings.

2:20pm **IA2-1-MoA-3 Ultra-High Vacuum Test System for Quantitative Determination of Hydrogen Permeability of Various Ceramic Coatings on Stainless Steel***, **Ewa Rennebro [ewa.ronnebro@pnnl.gov]**,* Pacific Northwest National Laboratory, USA **INVITED**

We will discuss a recently built state-of-the-art ultra-high-vacuum (UHV) test system with high accuracy and precision to quantify hydrogen uptake, solubility and diffusion in various materials. The design was developed by Pacific Northwest National Laboratory (PNNL) in collaboration with Vacuum Technology Inc (VTI). This automated UHV system can be used for several studies of hydrogen-metal interactions including absorption/desorption kinetics, thermodynamics, isotherms, plateau pressures, isotope studies, gaseous impurity identification and permeation rate. We will present recent permeation rate data of ceramics coatings to reduce permeation through stainless steel.

3:00pm **IA2-1-MoA-5 HIPIMS – Fascinating Technology to Make Next Steps in Tool, Decorative and Functional Applications***, **Philipp Immich [pimmich@hauzer.nl]**, Ivan Kolev, Andreas Fuchs, Daniel Barnholt, Julia Janowitz, Louis Tegelaers, Huub Vercoulen, Chinmay Trivedi, Geert-Jan Fransen,* IHI Hauzer Techno Coating B.V., Netherlands*; Holger Hoche, Thomas Ulrich,* TU Darmstadt, Germany*; Peter Polcik,* Plansee Composite Materials GmbH, Australia

The PVD (Physical Vapor Deposition) market is rapidly expanding into new application fields. To achieve these new applications, various PVD coating techniques are employed, with HIPIMS (High Power Impulse Magnetron Sputtering) being one of the most fascinating since its discovery. Over the past 25 years, numerous advancements have been made in latest Generation 3 - HIPIMS power supply technology, including modifications in bipolar mode, pulse shape, pulse length, pulse trains, and higher frequencies. Synchronization of cathodes and HIPIMS-based bias has also led to innovative PVD coating solutions.

Beyond the well-known performance improvements in HIPIMS-coated cutting tools, HIPIMS has demonstrated its potential for various other applications. We will showcase the ability to create different colors using HIPIMS technology and highlight its advantages for decorative applications on 3D products. For components, HIPIMS is an excellent tool for enhancing the wear and corrosion resistance of existing material systems. We will also present the latest coating development for cutting tools. Our presentation will illustrate how combining HIPIMS with new material systems can further expand and enhance potential application areas.

Decorative, tool and tribological markets are driven by production costs, making coating volume and size crucial factors. To meet these demands, we have scaled up our HIPIMS developments to deposit coatings on our largest industrial platforms, e.g. the Flexicoat 1500 to address market needs.

We will also provide an outlook on future developments and what can be expected next in the PVD market.

3:20pm **IA2-1-MoA-6 Inorganic Sputtered Coatings to Reduce Snow Friction for Cross-Country Skiing***, **Pauline Lefebvre [pauline.lefebvre@grenoble-inp.fr]**,* SIMAP, Grenoble-INP, CNRS, France*; Fabian Wolfsperger,* WSL Institute for Snow and Avalanche Research SLF, Switzerland*; Jean Herody,* FFS, France*; Matthias Jaggi,* WSL Institute for Snow and Avalanche Research SLF, Switzerland*; Arnaud Mantoux,* SIMaP, CNRS, University Grenoble Alpes, France*; Nicolas Coulmy,* FFS, France*; Pascal Hagenmuller,* Centre d'Etudes de la Neige, CNRM, Météo-France*; Elisabeth Blanquet,* SIMAP, Grenoble-INP, CNRS, France

In cross-country skiing, reducing the friction coefficient between the skis and snow is essential for sportive performance [1]. Fluorinated waxes, i.e. containing perfluoroalkyl (PFA) are known for their hydrophobic properties and were remarkably efficient in wet snow conditions. However, the International Ski and Snowboard Federation (FIS) has banned fluorinated wax since winter 2023/2024 -for health and environmental reasons [2]. Since then, no alternative with equivalent performance has been found. This project aims to develop hard and hydrophobic coatings based on titanium nitride (TiN), aluminum nitride (AlN) and alumina (Al_2O_3) materials directly deposited on ski bases and UHMW polyethylene. The role of coating surface properties and structure in friction is investigated

Thin films were deposited using DC and RF magnetron sputtering. The surface (contact angle, roughness, chemical composition), mechanical and thermal properties of the coatings were investigated. Friction coefficient of coated samples was evaluated on snow with a linear tribometer (speed: 0.1 m/s, displacement: 130 mm, contact pressure: 50 kPa). The tribo-system is therefore a 10cm-long coated ski sliding on controlled man-made snow in a cold-room at 0°C and dry air. Snow with different liquid water content were used for the tests.

Results are encouraging as deposition on ski base is feasible at ambient temperature with adhesive and dense coatings. Coating thicknesses were evaluated by scanning electronic microscopy between 50 and 200 nm depending on process parameters. Chemical analysis with XPS indicates nitride films contain a relative high amount of carbon and oxygen. Coatings, selected for their hydrophobicity and structural properties, were investigated in gliding tests. AlN and Al_2O_3-based coatings presented very high friction coefficient (0.2-0.3). TiN-based coating had the lower friction coefficient with a value of 0.11 on very wet snow, whereas a ski waxed with PFA friction coefficient was measured at 0.072.

To sum up, deposition of sputtered coatings was realized with success and may be a promising technique for preparing competition skis. For winter sport application, titanium nitride seems to be the most promising: it is indeed known for better mechanical properties [3] and lower thermal conductivity [4] which will be further investigated.

References:

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[3] Glocker, D. A. et al, Bristol, UK: Inst of Phys (1995).

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4:00pm **IA2-1-MoA-8 Influence of Corrosion on Wear and Brake Particle Emissions of Alumina-Coated and Uncoated Cast Iron Brake Discs**, ***Ran Cai* *[cai12r@uwindsor.ca]***, *Xueyuan Nie,* University of Windsor, Canada; *Yezhe Lyu Lyu, Jens Wahlström,* Lund University, Sweden

Hard coatings can be applied to cast iron brake discs to enhance wear and corrosion resistance and reduce brake particle emissions. This study investigated the influence of corrosion on brake particle emissions from cast iron discs through comparison of plasma electrolytic aluminized (PEA)-coated and uncoated surfaces. Six discs were subjected to corrosion in raining-snowy conditions for 24, 48, and 72 hours before undergoing tribological testing using a pin-on-disc tribotester combined with an airborne particle emission measurement system. The counterpart pins were machined from a commercially available low-steel (LS) brake pad. Data of particle concentration, size distribution, and total wear (disc and pad) were collected, while wear tracks, friction transfer layers and worn pad surfaces were analyzed using scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX). The results showed that the degree of corrosion of the uncoated disc increased with time, while the coated discs didn't show any corrosion sign. The corrosion products on the uncoated discs can be cleaned during the early stage of the tribotests where the particle emission was much higher than the later stage. The PEA coating effectively mitigated the effects of corrosion, resulting in significantly lower wear and brake particle emissions compared to uncoated discs. These findings demonstrate the potential of PEA coatings to reduce wear and emissions under winter conditions, offering benefits for environmental sustainability and public health.

4:20pm **IA2-1-MoA-9 The Effect of Mg Addition on the Corrosion Resistance of Two-Step Galvanizing Zn-5Al Coating**, ***Huan-Chang Liang* *[hcliang@niu.edu.tw]***, Department of Mechanical and Electro-Mechanical Engineering, National I-Lan University, Taiwan; *Yen-Kai Chen, Chaur-Jeng Wang,* Department of Mechanical Engineering, National Taiwan University of Science and Technology, Taiwan

The atmospheric corrosive substances like Cl^- ions or SO_3^{2-} ions make it easier for soluble zinc salts to form. Consequently, the introduction of more magnesium into the Zn-Al alloy bath enhances the formation of basic zinc salts that are susceptible to environmental corrosion. Zinc-aluminum carbonate hydroxide and aluminum-magnesium carbonate hydroxide are particularly notable corrosion products because of their stable and compact characteristics. Local acidity influences the rate of transformation of zinc hydroxide from zinc oxide, while the formation of $Mg(OH)_2$ mitigates the surface reduction of the galvanizing coating.

Although the Zn-5Al-2Mg coating is effectively produced using the continuous galvanizing process, the maximum coating thickness achieved is 20 μm. Numerous studies present their experimental findings about batch galvanizing zinc alloys. The coating structure is nonuniform, with an enrichment of iron content resulting from the elevated operating temperature, which inhibits the formation of a dense and continuous layer of corrosion products. Consequently, two-step batch galvanizing is utilized to provide a zinc alloy coating of adequate thickness. The initial process involves immersing samples in pure zinc, followed by immersion in zinc alloy. The coating's microstructure consists of an outer layer formed from zinc alloy and internal layers including an iron-aluminum intermetallic compound combined with a eutectic phase.

This study aims to examine the microstructure of two-step batch galvanizing Zn-5Al and Zn-5Al-2Mg coatings on low-carbon steel. The samples are produced by batch galvanizing pure zinc for 10 minutes, followed by batch galvanizing zinc alloy for 2.5 minutes. The corrosion resistance performance of both samples is evaluated by interfacial polarization and impedance matching. The microstructure of two-step galvanizing Zn-5Al and Zn-5Al-Mg consists of four distinct layered structures: a binary (Zn-Al) or ternary (Zn-Al-Mg) eutectic phase layer, a branch-like $FeAl_3$ phase layer, a dense $FeAl_3$ phase layer, and an internal eutectic phase layer. As the zinc content in the coating layer increases, there is a corresponding decrease in the charge transfer impedance (R_{ct}). This behavior is ascribed to the area fraction of the $FeAl_3$ phase in conjunction with the eutectic phase. The addition of magnesium into the zinc alloy bath enhances the R_{ct} of the entire coating layer. The advantageous effect arises from the disparity in corrosion potential between magnesium and zinc. Magnesium functions as a sacrificial anode for the Zn-rich phase, hence enhancing the effectiveness of cathodic protection.

Surface Engineering - Applied Research and Industrial Applications
Room Palm 1-2 - Session IA1-TuM

Advances in Application Driven Research and Hybrid Systems, Processes and Coatings

Moderators: Dr. Vikram Bedekar, Timken Company, USA, **Prof. Dr. Hana Barankova**, Uppsala University, Sweden

8:00am **IA1-TuM-1 Advancing Correlative Microscopy: In-Situ Integration of AFM-SEM-EDS for Multi-Modal Analysis***, **Kerim T. Arat [karat@qdusa.com]**, William K. Neils, Stefano Spagna,* Quantum Design Inc., USA

There is a growing interest in in-situ correlation microscopy, which brings the complementary strengths of different imaging modalities without the inherent complications of sample transfer. These approaches ensure high confidence in correlation accuracy and eliminate the risk of sample contamination and alteration during the sample transfer.

We have developed a correlative microscopy platform based on AFM-SEM [1]. These techniques can map the surface in high resolution, and the trunnion stage, with up to 80° tilt capability, allows monitoring of tip quality and tip-sample interaction [2]. However, these methods fall short in identifying the elemental composition of the sample.

To address this issue, we have extended the capabilities of the correlative platform with an energy-dispersive X-ray spectrometer (EDS). The spectrometer is based on a state-of-the-art silicon drift detector [3], which provides high energy resolution. Its graphene window offers improved transmission performance, especially at the lower energy range, allowing elemental detection down to carbon. The elemental identification algorithm uses a background subtraction method to remove non-characteristic signals and compares the resulting spectra to reference datasets based on the NIST database for standardless quantification [4]. Both hardware and software integration allow the correlation of elemental information with the other imaging modalities that the tool can provide (see the supplementary document), where one can superimpose topography and elemental information.

Integration of the X-ray detector adds a comprehensive analysis capability to AFM-SEM techniques applicable to a diverse range of fields such as materials science, semiconductors and biosciences. With this option, researchers can obtain an in-situ correlation of high-resolution, localized elemental information with high-resolution lateral and vertical topographical information.

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8:20am **IA1-TuM-2 Non-stick Hydrophobic and Superhydrophilic Metallic Coatings: Their PVD Fabrications and Applications***, **Jinn P. Chu [jpchu@mail.ntust.edu.tw]**,* National Taiwan University of Science and Technology, Taiwan

The presentation will begin with an introduction to a non-stick, low-friction hydrophobic metallic glass coating and its applications. This amorphous coating, fabricated using PVD techniques, has been successfully applied in various fields, including medical devices. For the superhydrophilic coating, a 316 stainless steel layer is sputtered onto the substrate, resulting in a water contact angle of approximately 10 degrees on the coated surface. This coating also demonstrates antifouling and underwater superoleophobic properties, which are advantageous for use in separation membranes for oil/water emulsions. Furthermore, it has proven highly effective in enhancing electrochemical responses in electrodes used as electrochemical sensors.

8:40am **IA1-TuM-3 Novel CO_2 Laser Direct-Write Energy-Efficient Process for Functional Oxide-Carbon Composite Coatings and Their Energy Applications***, **swati Jadhav [swatijadhav1602@gmail.com]**, Pratibha jadhav, Ishwari Belle, Anuradha Ambalkar, Supriya Kadam, Satishchandra Ogale,* Indian Institute of Science Education and Research, Pune, India

The performance and operational longevity of several energy devices such as Batteries, Fuel Cells, and Electrolysers critically depend on the chemical and physical functionality, micro (nano) porosity, and robustness of the specialized coatings on metal current collectors. A large number of methods are available to obtain such coatings, but these are chemically complex and generally energy intensive. Moreover, several of these methods do not allow concurrent control of porosity and surface chemistry that drive the overall process efficiency, especially in surface catalytic phenomena. In this work we show that CO_2 laser (wavelength 10.6 mm) induced surface processing allows an excellent parametric control on achieving the desired results and that too with a dramatic reduction of energy inputs vis a vis the conventional methods. The key control parameters include laser power density, scanning speed, and coating constitution/thickness. The laser surface processing method is intrinsically direct-write type in scanning mode and as such allows in-plane micro-gradient patterning. We will show and discuss the results of several interesting cases wherein the effectiveness of this approach is demonstrated for composite oxide-carbon coatings obtained by using biomass (or biomass-derived) precursors and functional binary oxide systems. The biomass precursors include furfural alcohol, lemon grass, sugarcane bagasse while the oxide systems include NiO, CuO, TiO_2. Use of urea and thiourea in the composite is also examined to achieve doping of nitrogen and Sulfur in carbon to enhance its conductivity. The resulting engineered coatings are studied for energy applications such as Anode-free (AF) Li and Na ion batteries, and Electrocatalysis for water splitting applications (oxygen evolution reaction, OER and Hydrogen evolution reaction (HER)). For AF batteries the laser processed coatings render low Li/Na nucleation overpotential, good columbic efficiency and cycling stability of up to 800 cycles limited by Li/Na inventory. In case of water splitting application as well superior properties are realized in terms of overpotential and stability.

9:00am **IA1-TuM-4 PVD Coatings for the Hydrogen economy - Applications, Testing and Production***, **Herbert Gabriel [h.gabriel@pvtvacuum.de]**,* PVT Plasma und Vakuum Technik GmbH, Germany **INVITED**

Green hydrogen could be the fuel of the future. Generated by electroysers powered by photovoltaics and used in fuel cells could be part of the solution to the human mankind’s problems with the climate change.

The harsh environments in electrolysers and fuel cells require components to be coated for corrosion resistance, electrical conductivity and other related properties..

Most of the components are made of stainless steel or titanium, but still need for their performance and long lifetimes up to 100.000 hours coatings with high performance properties.

Depending on the application, whether PEMWE, PEMFC, AEM, SOFCs, SOECs or others, thin coatings made of materials such as C, Ti, Cr, Nb, Au, Pt, Ir, MCO, Al2O3....... are deposited in the nanometer to a couple of micron range.

Preferred coating processes are magnetron sputtering, respectively HiPIMS, high power impulse magnetron sputtering to deposit highly adherent and dense coatings.

Most components of fuel cells and electrolycers to be coated are thin 2-dimensional structures in high quantity. For this reason high productive so-called in-line systems with vertical orientation are the preferred coating systems for double-sided deposition.

Apart from a number of other QC – tests, adhesion, corrosion and ICR (interface contact resistance) prior and after corrosion testing are essential properties to continually be tested and monitored.

Surface Engineering - Applied Research and Industrial Applications
Room Town & Country D - Session IA2-2-TuM
Surface Modification of Components in Automotive, Aerospace and Manufacturing Applications II

Moderators: Dr. Satish Dixit, Plasma Technology Inc., USA, **Dr. Jan-Ole Achenbach**, KCS Europe GmbH, Germany, **Masaki Okude**, Mitsubishi Materials Corporation, Japan

8:00am **IA2-2-TuM-1 2D Material-Based Coatings for Superlubricity in Dry Sliding and Rolling Contacts***, **Diana Berman [diana.berman@unt.edu]**,* University of North Texas, USA **INVITED**

Friction and wear-related failures are critical challenges for modern mechanical systems, affecting applications from microelectromechanical devices to automotive assemblies and biomedical implants. The pressing need to reduce these tribological failures has intensified efforts to design advanced coatings and lubrication solutions tailored to withstand extreme operating conditions. This presentation emphasizes our progress in the precise design of 2D material-based coatings, particularly those using graphene, molybdenum disulfide, and MXene, to achieve superlubricity—an ultra-low friction regime that greatly enhances component lifespan and efficiency.

By establishing a fundamental understanding of material interactions at sliding interfaces, we are able to develop coatings that not only improve performance but also contribute to the reliability and sustainability of tribological systems. These engineered coatings are evaluated for their tribological properties under a range of conditions, demonstrating that superlubricity can be achieved at the macroscale, under high contact pressure and shear conditions. We also propose experimental pathways to realize superlubricity in rolling-sliding contact conditions using solid-lubricant coatings, which could open new opportunities for industrial applications requiring highly durable, low-friction surfaces. Overall, this work lays the groundwork for next-generation tribologically optimized coatings, offering promising solutions for critical sectors reliant on advanced friction and wear management.

8:40am **IA2-2-TuM-3 Exploring Controlled Plastic Deformation as a Preferable Pre-Treatment for Enhanced Tribo-Mechanical Properties of Fundamental Industrial Materials: Design of Wear Resistant Surfaces/sub-Surfaces***, **Daniel Tobała [daniel.tobola@kit.lukasiewicz.gov.pl]**, Puneet Chandran,* Łukasiewicz Research Network – Krakow Institute of Technology, Poland*; Łukasz Maj, Jerzy Morgiel,* Institute of Metallurgy and Materials Science of Polish Academy of Sciences, Poland

The need for superior physical, mechanical and tribological properties in modern industrial applications has driven manufacturers to develop advanced materials or provide tailor-made/innovative solutions for utilizing existing high performance materials. Aerospace and automotive industries are known to employ innovative materials like modern steels, titanium alloys, advanced ceramics etc., to meet the exponentially growing demand for 'sustainable' materials, taking into account industrial and economic viability. However, an exclusive solution addressing the increased adaptability of these materials is always inadequate owing to the excellent mix of inherent physical and mechanical properties. Although industry favors a 'one solution' to all materials/problems approach, it is practically impossible to implement it in real time. In this study, we aim to strategically propose solutions to enhance the tribo-mechanical properties of well-known, critical industrial materials like titanium, ceramics (alumina/Si) and advanced steels (Vancron/Vanadis) - through the synergistic effects of cold working and thermo-chemical processing.

The substrates of all the materials were subjected to simple finishing processes like grinding, turning/milling followed by controlled burnishing and shot peening/micro-blasting. Low temperature gas/plasma nitriding formed the last stage of pre-processing. Detailed tribological studies were carried out on all the samples. The nanoscale characterization of the pre-processed samples and the wear track via SEM/TEM revealed the formation of a thin 'tribo zone' with improved tribo-mechanical properties. The nature of tribo zone formed in each material, based on the type of cold working along with thermo chemical treatment will be outlined for all the materials and presented in the conference.

Acknowledgments

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9:00am **IA2-2-TuM-4 Liquid Feedstock Thermal Spraying for Advanced Functional Coatings***, **Shrikant Joshi [shrikant.joshi@hv.se]**,* University West, Sweden **INVITED**

Thermal spraying with liquid feedstock offers an exciting opportunity to obtain coatings with characteristics vastly different from those produced using conventional spray-grade powders. The two extensively investigated variants of this technique are Suspension Plasma Spraying (SPS), which utilizes a suspension of fine powders in an appropriate medium, and Solution Precursor Plasma Spraying (SPPS), which involves use of a suitable solution precursor that can form the desired particles *in situ*. The advent of axial injection high power plasma spray systems in recent times has also eliminated concerns regarding low deposition rates/efficiencies associated with liquid feedstock. The 10-100 µm size particles that constitute conventional spray powders lead to individual splats that are nearly two orders of magnitude larger compared to those resulting from the fine (approximately 100 nm - 2 µm in size) particles present in suspensions in SPS or formed *in situ* in SPPS. The distinct characteristics of the resulting coatings are directly attributable to the above very dissimilar 'building blocks' responsible for their formation. This talk will discuss the advancements in suspension and solution precursor thermal spraying associated with axial plasma spraying, with specific emphasis on thermal barrier coating (TBC) and environmental barrier coating (EBC) applications. Prospects of liquid feedstock thermal spraying for addressing some other niche applicationswill be discussed through some illustrative examples. A further extension of deploying solutions and suspensions that involves use of hybrid powder-liquid feedstock combinations for thermal spraying will also presented. This approach can be used to elegantly deposit coatings with unusual microstructures to develop a wide array of composite coatings. The possibilities unplugged by such hybrid feedstock processing will also be illustrated through case studies.

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

Innovative Surface Engineering for Advanced Cutting and Forming Tool Applications

Moderators: Markus Esselbach, Oerlikon Balzer, Liechtenstein, **Dr. Christoph Schiffers**, CemeCon AG, Germany

1:40pm **IA3-TuA-1 Natural Rock Star: PVD-Functionalizing of Nature-Derived Materials for Cutting Applications***, Wolfgang Tillmann, **Dominic Graf [dominic.graf@tu-dortmund.de]**, Nelson Filipe Lopes Dias,* TU Dortmund University, Germany*; Bernd Breidenstein, Berend Denkena, Benjamin Bergmann, Hilke Petersen,* Leibniz Universität Hannover, Germany

The manufacturing process of traditional cutting materials such as cemented carbide involves significant energy consumption and costly raw materials that are often linked to environmental harm during extraction. To address these concerns, there is a growing demand for developing sustainable cutting materials. In this context, natural materials are both environmentally friendly and abundant. Natural rocks, in particular, are promising due to their hardness, which typically ranges from 8 to 16 GPa depending on the rock type. The suitability of these natural materials for machining can be enhanced via functionalization of the surface properties by applying a protective thin film using physical vapor deposition (PVD) technology.

Preliminary studies show the suitability of various rock types as cutting material. Cutting inserts are crafted from these natural rocks and subsequently ground. A TiN thin film is deposited onto the various natural rock inserts using a magnetron sputtering process. The resulting TiN thin films crystallize in a cubic structure on all rock types. The obtained hardness values are comparable to TiN thin films grown on tool steel. In contrast to a polished surface, a ground surface of the natural rocks promotes good adhesion of the TiN thin films. To assess the cutting performance and wear characteristics of PVD-coated natural rocks, turning tests are conducted using the aluminum alloy Al7075. The TiN thin film significantly enhances wear resistance, thus extending the service life of the cutting inserts. Additionally, it is observed that the distinct material properties of the natural rocks significantly affect the wear behavior. Rock types with a more homogeneous structure demonstrate improved wear resistance over extended cutting lengths.

To analyze the effect of the substrate on the TiN thin film adhesion three different glass substrates were chosen as surrogates for natural rocks. Glasses are particularly suitable as surrogates because of their similar SiO2 content. The investigations reveal a strong influence of the stress state on the adhesion, as TiN on window glass shows weaker adhesion due to high compressive residual stresses. The possible adaptation of thin film design strategies developed for glass onto natural rock surfaces is evaluated. The utilization of a PVD-coated natural rock emerges as a promising concept for broadening the spectrum of cutting materials and promoting sustainability in their manufacturing. A tailored adjustment of the grinding process for cutting inserts with an adapted thin film design is anticipated to further elevate the cutting performance of natural rock inserts.

2:00pm **IA3-TuA-2 Properties and Metal Cutting Performance of High Entropy Nitride (HEN) and HEN-MN Coatings***, **Abhijit Roy [abhijit.roy@kennametal.com]**, Brittany Macshane,* Kennametal Inc., 1600 Technology Way, Latrobe, PA 15650, USA*; Joern Kohlscheen,* Kennametal GmbH, Altweiherstr. 27, 91320 Ebermannstadt, Germany*; Dev Banerjee,* Kennametal Inc., 1600 Technology Way, Latrobe, PA 15650, USA

Hard and wear protective coatings are normally deposited on cutting tools to improve their metal cutting performance and lifetime. These coatings, depending on metal cutting conditions and workpiece materials, often require specific properties which are difficult to achieve by conventional (using binary, ternary or quaternary) nitride coatings. High entropy nitride (HEN) coatings, with disordered multi-cations sublattice and ordered anionic sublattice, show many remarkable properties including high thermal stability induced by entropy stabilization, high hardness, and fracture toughness originating from multiple-elemental lattice distortions and impeded dislocations, as well as excellent corrosion resistance caused by sluggish diffusion. Moreover, multilayer and superlattices of HEN containing layers allow an additional degree of design-flexibility to improve fracture toughness and other properties. This work investigated crystalline structure and morphology, residual stresses, adhesion, mechanical properties and metal cutting performance of cathodic arc plasma deposited thin films of HEN and HEN-MN. The HEN target contains five different elements from groups IV, V and VI of the periodic table and the target for MN contains a single transition metal element. X-ray diffraction results indicate presence of two NaCl type FCC phases for both the single layer HEN and multilayer HEN-MN coatings. The residual compressive stress value of the films does not change much with increase in deposition bias voltages. Nanohardness values of the films were found be in the range of 32-35 GPa and bulk modulus values of the multilayered HEN-MN coatings were slightly higher than the single layered HEN coatings. No correlation was found between the scratch adhesion or indent adhesion strength and substrate bias voltages. Scanning electron microscopy (SEM) images of the coatings show deposition of dense HEN coatings and formations of nanolayers in case of HEN-MN coatings. The elemental analysis using energy dispersive x-ray (SEM-EDX) indicates formation of nitrogen deficient sub-stoichiometric nitrides for both the single layer HEN and multilayer HEN-MN coatings. Turning tests with coated carbide inserts using IN718 as workpiece material showed promising tool life compared to conventional AlTiN coatings.

2:20pm **IA3-TuA-3 Surface Engineering of AlCrN-Coated Carbide through Laser Texturing for Performance Enhancement***, **Yassmin Seid Ahmed [yassminm66@gmail.com]**,* KFUPM, Saudi Arabia

Utilization of coating and surface texturing techniques combines to great effect to further enhance the overall performance of carbide surfaces. For these materials, adhesion is most critical in defining the performance of the coating. Poor adhesion and coating quality can lead to eventual failure. With cemented carbide being one of the materials of concern, LST has gained much attention as having superior mean coating adhesion. However, the effects of the combined processes of coating followed by texturing and texturing followed by coating and their interactions remain poorly understood.

This study analyzes micro-structured coated cemented carbide surfaces prepared from varying processes and property conditions while examining their surface characteristics and friction performance. The performance of the substrates, which had undergone surface treatments followed by ball-on-disk tests, was then evaluated and compared. The coated surface sample, where surface texturing was done first and coating applied afterward (AC), showed better microhardness, more refined microstructures, and better wear resistance than the coating surface first, followed by surface texturing (BC). Although the sample coated was found to show superior hardness values across the board, the AC sample displayed more favourable results in other areas. A prime example is that the AC sample was 12% more microhard than the coating sample, although the overall hardness was reduced by 3%, coupled with a reduction in friction force by 8%.

It creates an insightful mark to realize that the order of application of the texturing and coating processes would bear significant relevance in affecting the final performance of the material. This study now stresses that enhanced adhesion and wear resistance were found in the coating substrate wherein the texturing technique was performed first and then coated (AC) as being very consistent in proposing that these combined techniques can make way into producing contributions toward more durable and effective coatings for industrial usages.

2:40pm **IA3-TuA-4 Advanced Cyclic Load Resistance of AlXN Coatings for Metal Forming Applications***, **Simon Evertz [simon.evertz@eifeler-vacotec.com]**, Stefan A. Glatz, Tobias Oellers, Markus Schenkel,* voestalpine eifeler Vacotec GmbH, Germany

Cyclic loading is critical for the industrial application of PVD coatings, especially in metal forming applications. With the increasing interest in using thin super-high-strength steel sheets for forming bodies/parts with reduced component weight, light-weight design and less fuel consumption could be achieved for example in automotive industry. Consequently, the loads become more demanding on molding dies and therewith protective coatings. These applications require coatings resistant to cyclic mechanical and/or thermal loading and fatigue. The specific structure of voestalpine eifeler's Duplex-VARIANTIC®-1400-plus with its multiple hard material AlXN layers overcomes the very demanding requirements in terms of strength, hot-hardness, and load-bearing capacity in such metal forming applications and outperforms other commercially used hard nitride protective coatings. This property profile makes voestalpine eifeler's Duplex-VARIANTIC®-1400-plus the optimal solution for metal forming high-strength and advanced high-strength steel sheets.

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 Metallurgical Coating by Laser Metal Deposition of H13 Steel Powder for Die Repairs*, **Sheila Carvalho [sheila.m.carvalho@ufes.br]**,* Federal University of Espirito Santo, Brazil*; Vagner Braga,* Bruning Tecnolometal Co., Brazil*; Rafael Siqueira, Kahl Zilnyk,* Technological Institute of Aeronautics, Brazil*; Johan Nuñes,* University of Sao Paulo, Colombia*; Reginaldo Coelho,* University of Sao Paulo, Brazil*; Milton Lima,* Institute for Advanced Studies, Brazil

The H13 tool steel is a typical hot-work material that exhibits superior thermal resistance, excellent hardness, and exceptional resistance to high-temperature fatigue and wear. This steel is also characterized by its high resistance to softening at temperatures below 540 °C and is extensively used to produce hot forging dies, hot extrusion channels, and high-pressure dies for low-melting-point metals such as aluminum and magnesium. Components made of H13 steel wear out over time and must be replaced, generating high costs and considerable environmental impact. One way to mitigate these problems is through repair using metallurgical coatings, which involve machining the worn area of the tool and depositing one or more layers of H13 steel using thermal means, notably with a laser beam. In this study, the microstructural and mechanical properties of H13 powder deposited via laser metal deposition (LMD) on H13 hot-work tool steel substrates were examined before and after heat treatment. Scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), and electron backscatter diffraction (EBSD) were used to analyze the grain distribution, layer development, and carbide incidence. The mechanical properties were evaluated by Vickers hardness indentation tests. An α-ferrite matrix consisting of α'-martensite was identified along with a crack-free interface containing Mo- and Cr-rich precipitates between the cladded H13 steel and substrate. The EBSD results showed a highly consistent combination between the deposition and substrate, along with a structure consisting of columnar and equiaxial grains resulting from the directional solidification process. Wear resistance tests demonstrated that the H13-deposited region was in a better condition than the substrate because of the presence of martensite and carbides in the matrix, and the average wear decreased from 3.8×10^{-4} mm^3/Nm to 0.5×10^{-4} mm^3/Nm from the substrate to the laser cladding. The measured coefficient of friction for the die-repaired H13 rods did not undergo significant changes after laser cladding, with a COF of ~ 0.8. The average hardness levels of the substrate and deposition regions were determined to be 213 HV (α-Fe) and 671 HV (α'), respectively. The smooth transition in terms of hardness between the regions also indicates a tendency for lower stress concentrations. The results indicate that metallurgically coated H13 steel could be used to repair hot forming tools that extend the lifetime and decrease the discard of high-value components.

IA-ThP-2 Effects of Cathodic Current Density on the Growth Mechanism and Corrosion Resistance of Micro-Arc Oxidation Coatings on AZ31 Magnesium Alloy*, **Shih-Yen Huang [f08525129@g.ntu.edu.tw]**, Chi-Hua Chiu, Yu-Ren Chu, Yueh-Lien Lee,* National Taiwan University, Taiwan

Despite decades of development, many growth mechanisms and properties of the micro-arc oxidation (MAO) process remain unclear, limiting further advancements in this surface treatment. Numerous studies have identified trends in MAO process parameters under specific conditions; however, altering these conditions often leads to varied results, highlighting the need for in-depth mechanistic studies. In this study, we address aspects of the formation mechanism of MAO under cathodic bias control. Preliminary results show that, while maintaining the electric current at a constant value, varying the cathodic current density significantly affects the microstructure and anti-corrosion properties of MAO coatings on AZ31B Mg alloy. Specifically, when the cathodic current density exceeds the anodic current density, a distinct cross-sectional microstructure develops, leading to a significant decrease in corrosion resistance. These findings demonstrate that the instantaneous cathodic current density critically influences the growth path of MAO coatings, altering their microstructure and, ultimately, their corrosion resistance.

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