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.

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