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.

Author Index

Bold page numbers indicate presenter