Surface Engineering - Applied Research and Industrial Applications
Room On Demand - Session G2

Surface Modification of Components in Automotive, Aerospace and Manufacturing Applications

G2-1 INVITED TALK: Enhancing TiAl Oxidation Resistance at High Temperature: A Challenge for the Aerospace Industry*, Marjorie Cavarroc (marjorie.cavarroc@safrangroup.com),* Safran Tech, France **INVITED**

The 21st century is one of major importance for the aerospace industry because of the important increase in flight demands from the Asian market. Evaluated at 3.8 billion in 2016 by the International Air Transport Association (IATA), the number of airplane passengers is predicted to double by 2037. To supply to the rising demand, to mitigate operation costs, and to reduce the environmental impact of such air traffic, aircraft designs are pushed to technological limits. This is particularly true for the engines, whose efficiency is dictated by their thrust-to- weight ratio. Judicious weight reduction combined with the elevation of engines' operating temperatures will therefore improve their efficiency.

In this context, titanium aluminides (TiAl) attract immense interest because of their low weight and their high specific strength at high temperature compared to conventional titanium or nickel alloys. This allows for the manufacture of lighter blades and the reduction of the mass of other components.

TiAl are intermetallic compounds. Their ordered structure and strong atomic bonds give them good mechanical properties and good oxidation resistance. These properties are almost of the same order of magnitude as the ones of Nickel-based alloys. They also have a lower density than Nickel based alloys (3.9 to be compared to 8.3), that could allow a significant weight reduction of the engines. However, intermetallic compounds are known to be brittle and to have low toughness.

Presently, TiAl is used for application parts exposed to temperatures lower than 750°C. Above this temperature, mechanical properties are severely reduced. The range of temperature at which severe oxidation appears is between 750 °C and 850 °C, depending on the alloy.

The oxygen embrittlement and the ductility loss of TiAl alloys are commonly considered as a subsurface effect due to the uptake of oxygen into the α2 phase. The γ phase has a low oxygen uptake, can act as a barrier against oxygen and has better mechanical properties than the α2 phase.

Up to now the most promising approach to protect γ-TiAl-based alloys against environmental degradation at temperatures as high as 1000 °C is surface engineering. By decoupling bulk and surface properties, it allows the protection of various types of materials against environmental degradation without impacting their carefully designed composition.

A large study, including PVD, PECVD and electrochemical deposition, was performed in order to find a way to protect efficiently TiAl at high temperature. A review of this study will be presented and performances of the different coatings will be compared.

G2-3 Electrolytic Plasma Polishing as Post-Treatment for Additively Manufactured Stainless Steel*, Nicolas Laugel (nicolas.laugel@manchester.ac.uk),* *A. Matthews, A. Yerokhin,* The University of Manchester, UK

The Additive Manufacturing (AM) of metals promises disruptive changes in a host of manufacturing industries. While the field has been advancing at a rapid pace over the past years, resulting surface states remain a particularly unyielding obstacle to a wide range of applications. Powder particle sizes in the tens of micrometres impose similarly sized features on AM surfaces, with obvious negative impacts on mechanical performance or dimensional precision.

Electrolytic plasma polishing (EPPo) is a finishing method used for the polishing, cleaning, deburring, smoothing of metals and alloys. In contrast with other finishing techniques requiring careful control of directionality, such as mechanical polishing or laser-based methods, EPPo natively effects the surface as a whole. Among other geometry-independent approaches, such as electropolishing or chemical etching, EPPo stands out with its benign water-based electrolytes, low material removal for a given target surface state, and treatment times in the minutes. With these characteristics, the method complements AM particularly well, with few or no constraints put on piece design as well as ease of application for industrial actors who do not necessarily have experience in hazardous chemical handling and waste management.

The work presented here focuses on two complementary approaches for in-depth characterization, of the process itself and of the resulting surfaces respectively, with the ultimate goal of streamlining the optimization of EPPo on an application-by-application basis. In situ analysis of the process could enable the automated fine-tuning of parameters through direct feedback. To help realize this, comprehensive analyses in the frequency domain of the electrochemical cell current response were conducted and shown to give real-time information on the balance between the different reactions and physico-chemical phenomena at play. Additionally, plasma light emission and gas evolution were analyzed to inform interpretation and the role of the different process parameters.

Extensive ex situ analysis of the surfaces was performed in terms of morphology and composition. Very superficial dealloying (~10nm) could be demonstrated in the case of Ni-Cr steels which, along with the overall roughness decrease, is believed to drive moderate improvements in corrosion resistance and microhardness. Surface profilometry over macroscopic areas was used to determine the strength of the smoothing effect as a function of the lateral size of features, a metric particularly pertinent to the finishing of AM pieces and their large-scale surface roughness.

G2-4 PEO Coatings for Adhesive Bonded AA6060 Components*, Dominic Shore (dominic.shore@manchester.ac.uk),* The University of Manchester, UK*; J. Avelar-Batista Wilson,* BCW Manufacturing Group Ltd, UK*; A. Matthews, A. Yerokhin,* The University of Manchester, UK

Adhesive bonded aluminium components have become increasingly important to the automotive industry, where lightweight structures are imperative to performance and vehicle efficiency. Since the mid-20th century, conventional anodizing processes have been applied to aluminium components subject to adhesive bonding, to increase bond durability and corrosion resistance. However, conventional anodizing generally uses strongly acidic electrolytes which have a significant environmental impact. Anodizing procedures are generally multi-stage processes which can be resource intensive and time consuming. This study looks into application of Plasma Electrolytic Oxidation (PEO) as an alternative to conventional anodizing techniques for the preparation of aluminium parts for bonded structures. PEO is a promising emerging coating technique for the production of oxide coatings with excellent tribological performance and corrosion resistance. It offers an alternative route for the production of well adhered oxide coatings where weak alkaline electrolytes can be utilised in place of the highly acidic electrolytes associated with conventional anodizing processes. PEO has the further potential to reduce the number of additional treatments prior to and after the anodizing stage, offering scope for savings in resources and time.

In this investigation, experiments were carried out to produce PEO coatings on the alloy AA6060-T6 using different electrolyte compositions and power/polarity regimes, to develop coatings with differing characteristics for comparison. Detailed analyses of the microstructure, chemical and phase composition of these coatings was carried out using methods including SEM, EDS, GDOES and XRD. The adhesive strength of coatings was assessed using mechanical tests including tensile lap-shear testing. Analysis of the fracture behaviour and the ultimate strength of the adhesive joints was considered along with the observed physical/compositional characteristics of the different coatings to determine the suitability of PEO coatings for bonding applications and to achieve an understanding of the important parameters influencing the joint strength when bonding PEO coated AA6060-T6. The coatings were further investigated using electrochemical techniques such as EIS and subjected to accelerated corrosion testing along with investigations into the abrasive wear of the coatings to determine their overall suitability for automotive applications. It is intended that the findings of this study will be of interest for potential industrial applications and will also contribute to the general understanding of the mechanical properties of PEO coatings.

G2-5 Cobalt-based Thin Films as Electrocatalysts for Water Recombination Applications, ***Clara Linder (clara.linder@liu.se)***, Linköping University, IFM, Nanostructured Materials, Sweden*; S. Gangaprasad Rao, A. Le Febvrier,* Linköping Univ., IFM, Thin Film Physics Div., Sweden*; S. Munktell,* Swerim AB, Sweden*; P. Eklund,* Linköping Univ., IFM, Thin Film Physics Div., Sweden*; E. Björk,* Linköping University, IFM, Nanostructured Materials, Sweden

Catalysts and electrocatalysts are crucial for energy production and storage solutions. Water recombination is one important reaction for these applications, but due to sluggish kinetics, an electrocatalyst is required. Cobalt oxides have presented good performances for the oxygen reduction reaction (ORR) [1], and in some cases as good as noble metal-based catalysts [2]. To develop cost efficient systems and functionalized surfaces, the catalysts can be synthesized as nanomaterials or thin films.

In this work, cobalt thin films were deposited on low alloyed steel using magnetron sputtering. The thickness of the film was estimated to 200 nm with cross-section scanning electron microscopy (SEM) analysis. Co-films were then electrochemically oxidized at room temperature in an alkaline solution. The final material was a multi-layered mix of cobalt oxides, one of them being Co_3O_4 identified with X-Ray Diffraction (XRD). The catalytic performances of the oxidized films were evaluated in 1M KOH electrolyte saturated with oxygen. Cathodic currents in 10-50 mA/cm^2 range, corresponding to ORR activity, were measured with linear scan voltammetry. Different characterization techniques (SEM, XRD and X-ray photoelectron spectroscopy) were used to define the material properties of the thin films and its catalytic activity.

This work has shown that thin films can be used as electrocatalysts, after electrochemical modification, efficiently for oxygen reduction reaction for energy production and storage solutions.

[1] P. C. M. Hamdani , R.N. Singh, “Co3O4 and Co- Based Spinel Oxides Bifunctional Oxygen Electrodes,” Int. J. Electrochem. Sci., vol. 5, pp. 556–577, 2010.

[2] P. W. Menezes et al., “High-Performance Oxygen Redox Catalysis with Multifunctional Cobalt Oxide Nanochains : Morphology-Dependent Activity,” ACS Catal., vol. 5, pp. 2017–2027, 2015.

Author Index

Bold page numbers indicate presenter