Tribology and Mechanical Behavior of Coatings and Engineered Surfaces

Room Royal Palm 4-6 - Session E3

Tribology of Coatings for Automotive and Aerospace Applications

Moderators: Sebastien Guimond, Oerlikon Balzers, Oerlikon Surface Solutions AG, Nicolas Argibay, Sandia National Laboratories, Christian Greiner, Karlsruhe Institute of Technology (KIT), Institute for Applied Materials (IAM)

2:10pm **E3-3 Cladding Tribaloy T400 on Steel Substrates using a High Power Nd:YAG Laser***, **Wei Ya**, B Pathiraj, D Matthews,* University of Twente, Netherlands*; M Bright,* Tata Steel, Netherlands*; S Melzer,* Tata Steel Research & Development, Netherlands

Tribaloy T-400 is a Cobalt and Molybdenum based alloy, which has been developed for the resistance to high temperature wear, galling and corrosion. Its hardness is provided by a hard inter-metallic Laves phase, dispersed in a tough matrix of eutectic or solid solution. However cracking during processing limits its application such as hard facing using laser surface cladding/coating, especially when a Nd:YAG laser is applied as is commonly available in industry. The primary aim of this work is accomplished by laser cladding crack-free Tribaloy T-400 layers using a high power Nd:YAG laser. The optimal process conditions of cladding crack free Tribaloy T-400 coating on different steel substrates (st355J2 steel plates and AISI 316 steel bar) were obtained. The dilution effects on the hardness of cladded Tribaloy T-400 coating are investigated. Microstructures of the clad layer produced with optimal process parameters with and without preheating substrate were analysed by using Scanning Electron Microscope (SEM). The chemical compositions of different phases in the clad were analysed by using Energy Dispersive X-ray Spectroscopy (EDX). The resulting Austenite, Ferrite and Laves phases present in the clad were analysed by using X-ray Diffraction (XRD). The residual stress in the clads were evaluated by using hole drilling and XRD techniques. The correlation between the process conditions and resulting microstructures are discussed to provide guidelines for further up-scaling of laser clad crack-free Tribaloy T-400.

2:30pm **E3-4 Tribological Properties of HVOF-Sprayed WCCoCr Coatings for Applying to Sliding Rings of Mechanical Seals***, **Aleksander Iwaniak**,* Silesian University of Technology, Poland*; G Wieclaw,* Certech Sp. z o.o., Poland*; L Norymberczyk,* ANGA Sp. z o.o., Poland

The critical elements of mechanical seals are sliding rings. In almost all applications constructions, at least one of these rings is made of tungsten carbide or silicon carbide, usually in the form of a solid ceramic. The paper presents the results of research on the development of a new generation of sliding rings with a metallic core and a working face covered with coating using HVOF thermal spray technology with the use of WCCoCr ultra fine powder. The metallic core of the ring provides very good mechanical properties, including impact resistance, while the heat-sprayed carbide coating allows for wear resistance comparable to that made of solid ceramic. The tests were conducted with the "ring on ring" method for time 400 hours. The specimens "ring" were made of various materials: carbon-graphite material and a tungsten carbide. The condition of the top layer of the specimens was determined after the friction tests (3D profilometry, SEM). Laboratory tests of the new generation of slip rings and preliminary tests in industrial conditions have shown that the developed solution is characterized by high durability and has high application potential.

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2:50pm **E3-5 The Effects of Relative Humidity on Fretting Corrosion Behaviors of Silver-plated Electrical Contacts***, **Florent Pompanon**, S Fouvry,* LTDS, CNRS UMR 5513, Ecole Centrale de Lyon, Ecully, France*; O Alquier,* PSA, Vélizy – Villacoublay, France

During the last decades, the use of connectors in electrical devices for automotive has increased significantly. This raise in the number of electrical and electronic devices on board cars has led to a growing number of breakdowns. Indeed, this connectors need to keep a low and stable electrical contact resistance (ECR) otherwise micro-interruptions of signal may occur. Due to their work environment (car engine) they are subjected to vibrations inducing fretting in the contact.

Fretting occurs at the interface of materials in contact and refers to small oscillatory motion between the two surfaces. This phenomenon induces wear and the formation of oxide debris layer (third body) in the contact area increasing the electrical contact resistance.

The damaging effect on electrical contacts has been widely studied, a lot of studies have been conducted on non-noble materials (such as tin-plated contact) and noble materials (gold-plated and silver-plated contact) to determine the mechanisms of electrical contact damage and predict the electrical contact resistance endurance (ECR endurance)[1], [2].

The aim of this study is to consider the effect of the relative humidity rate on fretting behavior of silver-plated electrical contact. A climatic generator is used to work in a range of relative humidity (RH) from 10 % to 90 %.

The results show that the relative humidity rate impact the electrical contact resistance endurance. The number of cycles to reach the electrical failure (Nc) of the contact increase substantially, and especially when the relative humidity is above 50 %. Two behaviors can be highlighted, a threshold RH_{th}=50% as been established marking the transition between the two regimes :

1. When RH < 50% :

- A rather constant evolution is observed, the ECR endurance remains stable.

- The third body layer is formed of pulverulent oxides displaying a low current conductivity . They are easilly ejected from the interface. This implies a high wear rate and a low ECR endurance.

1. When RH > 50% :

- The ECR endurance strongly increases : the larger the relative humidity the large the ECR endurance (linear increase).

- The formation of oxide – hydrate is activated. The third body is more compacted and adherente to the interface (uneasy third body ejection), the wear rate is decreased. Moreover, hydrates displays a lower coefficient of friction and high current conductivity extending the ECR endurance.

These hypotheses are discussed regarding the mechanical, chemical and electrical characterization of the debris layer.

References:

1. S.Fouvry, P. Jedrzejczyk, P. Chalandon, Wear 271, 2011, 1524-1534

2. J.Laporte, O. Perinnet, S. Fouvry, Wear 330-331, 2015, 170-181

3:10pm **E3-6 Evaluation of Solid Particle Erosion Resistant Coatings for Gas Turbine Engine Applications***, **Qi Yang**,* National Research Council of Canada, Canada

Aircrafts, when operating in a sandy environment , can experience severe erosion damage to gas turbine engine components, such as compressor blades, vanes and impellor blisks/wheels, due to sand particle ingestion. As erosion progresses, a significant amount of material removal not only leads to significant aerodynamic losses, but results in the structural weakening of blades as well. Applying erosion resistant coatings on airfoil surface has been proven effective in extending the serviceable life of engine components. In the course of coating development, the adequate erosion testing techniques have to be applied in order to identify potential candidates economically and under representing conditions. From this perspective, various erosion testing techniques are first reviewed for their pros and cons. Then, proper testing protocols and evaluation methods of erosion resistance are elaborated based on testing results of TiN coating and another proprietary erosion resistant coating using gas jet apparatus. Taking the consideration of aerodynamic factors to erosion performance, wind tunnel sand erosion testing is also performed on the coatings. The results of gas jet and wind tunnel erosion testing are compared and discussed. Furthermore, several technical concerns related to erosion resistant coatings are deliberated.

3:30pm **E3-7 Influence of Sliding Induced Defects on the Frictional Properties of Molybdenum Disulfide (MoS_2) and Graphene***, **Zaixiu Yang**, S Bhowmick, G Sun,* University of Windsor, Canada*; F Sen,* Argonne National Laboratory, USA*; A Alpas,* University of Windsor, Canada

2D-layered structures MoS_2 and graphene show low coefficient of friction (COF) during initial sliding contact (running-in period), but their long-term tribological performance depend on the moisture in the testing

environment. Sliding induced defects contribute differently to frictional properties of MoS_2 and graphene under humid environments. Micro-Raman spectroscopy indicated that sliding induced structural defects in graphene, but graphene showed a low friction under humidity while a higher friction in dry N_2. Using van der Waals interaction incorporated Density Functional Theory (DFT) calculations, it was found that dissociative adsorption of water molecules at a mono-vacancy site of the graphene led to the increase in the graphene layer spacing and reduced interlayer adhesion energy, and thus contributed to the reduced COF. Meanwhile, the MoS_2 tested under humid environment showed a high friction whereas a low friction in dry N_2 was observed. Results of DFT calculations suggest the possibility of formation of Mo-O-Mo by the dissociated water molecules at triple vacancy site, resulting in the increase in COF as will be discussed in the conference.

3:50pm **E3-8 Analysis of Tribo-mechanical Behavior of a Low Temperature Plasma Nitrided Austenitic 316L Stainless Steel**, *J Oseguera,* ITESM-CEM, Mexico*; R Meza,* TEROMOINNOVA, Finland*;* ***Fernando Santiago****,* ITESM-CEM, Mexico

Microstructure of AISI 316L nitrided steel, treated by a weak ionized plasma process, using N2,H2 and Ar gas mixtures, was analyzed. Active nitrogen in the plasma that correlates to the diffusion of nitrogen in the steel is identified by optical emission spectroscopy. The kinetic evolution of expanded austenite was identified by treatments developed at low temperatures bellow the eutectoid transformation temperature. Phases obtained on surface were identified by XRD, from cross sectional views obtained by optical microscopy the thickness of expanded austenite was measured. Vickers hardness profile from surface was measured. Analyses of tribo-mechanical behavior of steel in a pin-on-disk system, for nitrided and non-nitrided steels samples, were used to contrast friction coefficients. The response of the tribo-mechanical system was interpreted through the structural characterization of the steel.

4:10pm **E3-9 Tribological Systems Solutions for Gas Turbine Engines***,* ***Pantcho Stoyanov****, A Wusatowska-Sarnek, T Kasprow,* Pratt & Whitney, USA **INVITED**

The advancement of durable gas turbine engine components depends heavily on the development of high-performance materials, which can withstand extreme environmental and contact conditions (e.g. large temperature ranges, high contact pressures, and continuous impingement of abrasive particles, all of which degrade the physical properties). In particular, due to the large number of complex contacting and moving mechanical assemblies in the engine, the lifetime of certain structures is limited by the tribological performance of the employed materials and coatings. This talk will provide an overview of tribological solutions employed in several sections of gas turbine engines. After a general review of aircraft engine tribology, the talk will focus on coatings used for clearance control (i.e. abradable air seals) as well as tribological materials used to minimize fretting type of wear. More specifically, a study will be presented on the influence of self-lubricating hexagonal boron nitride (hBN) on the erosion and abradability of Ni-based abradable coatings. Subsequently, a series of studies on the friction and wear behavior of Ni-based and Co-based superalloys at elevated temperatures will be presented. Emphasis will be placed on the correlation between the third body formation process (e.g. oxide layer formation, transferfilms) and the tribological behavior of the superalloys. This talk will conclude with a discussion of the needs for tribological coating solutions in gas turbine engines.

4:50pm **E3-11 The Friction and Wear Performance of DLC Coatings Deposited on Plasma Nitrided AISI 4140 Steel by Magnetron Sputtering under Air and Vacuum Conditions***,* ***Halim Kovacı****,* Atatürk University, Turkey*; O Baran,* Erzincan University, Turkey*; A Yetim,* Erzurum Teknik University, Turkey*; Y Bozkurt, L Kara,* Erzincan University, Turkey*; A Çelik,* Atatürk University, Turkey

Diamond-like-carbon (DLC) coatings with high hardness and low friction coefficient exhibit excellent tribological performance under air and vacuum conditions. However, adhesion and cold welding problems in vacuum conditions lead to increase friction coefficient values. These negative effects can be eliminated by different methods such as forming interlayers between coating and substrate or ion treatment of the substrate. In this work, DLC coatings were deposited on untreated and plasma nitrided (at 400 °C, 500 °C and 600 °C for 1h and 4h) AISI 4140 steel substrates by magnetron sputtering technique. The effects of plasma nitriding treatment on the friction and wear properties of DLC coatings under air and vacuum conditions were investigated. The structural and mechanical properties of DLC films were examined by XRD, SEM, and microhardness tester, respectively. The friction and wear properties were determined by a tribotester under air and vacuum conditions. The microhardness of samples increased after surface treatments and the highest value was obtained from the sample plasma nitrided at 600 °C for 4h plus DLC coated sample. The wear resistance of samples increased with increasing plasma nitriding time and temperature. Also, it was observed that the samples tested under vacuum condition showed better wear resistance than the samples tested under ambient air. Furthermore, increasing plasma nitriding time and temperature improved the wear performance of the material regardless of the test environment.

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