Surface Engineering - Applied Research and Industrial Applications

Room Town & Country C - Session IA2-2-TuA

Surface Modification of Components in Automotive, Aerospace and Manufacturing Applications II

Moderators: Vikram Bedekar, The Timken Company, USA, **Satish Dixit**, Plasma Technology Inc., USA

2:00pm **IA2-2-TuA-2 Impact of Novel Thermal Spray Material Solutions for Future Aerospace Applications and the Impact on Sustainability for the Environment and Business***, **Matthew Gold (matthew.gold@Liberty.Rolls-Royce.com)**,* Rolls-Royce North America **INVITED**

This presentation discusses the sustainability of materials and processes as applied to surface solutions in gas turbine engines.With the Aerospace industry under increasing pressure to improve the environmental performance of gas turbines, there is a growing need to reduce emissions and improve efficiency.This paper will outline the challenges associated with conventional materials and processes as well as the future materials that are being considered.

With an increase in turbine temperatures industry is moving towards more advanced materials systems for survivability.Over the last decade, industry has increased its use of rare earth oxides in thermal barrier coatings to help overcome the challenge of survivability in this harsh environment.This advance in materials comes with an impact on sustainability for the environment and business.

This presentation discusses these advanced materials for future applications and the challenges that will be encountered for sustainability.This will include raw materials, abundance, availability, and the need to understand the impact of process efficiency on their usage.

2:40pm **IA2-2-TuA-4 Evaluation of Thick Erosion-Resistant TiCrN Coating Deposited on Engine Impellers***, Q. Wang,* The University of British Columbia; Aurora Scientific Corp, Canada*; L. Hsu,* Aurora Scientific Corp, Canada*; **Da-Yung Wang (dayung.wang@ubc.ca)**,* The University of British Columbia, Canada; Aurora Scientific Corp, Canada; SurfTech Corp, Taiwan;, Canada

Metal-nitride hard coatings deposited through physical-vapor-deposition (PVD) techniques are increasingly being utilized in aircraft engines to protect compressor components against erosion caused by sand particles. Among these coatings, TiCrN, a ternary nitride coating with nano-layered configuration, exhibits promising results for application on turbine engine impellers to enhance erosion resistance. However, the deposition of TiCrN on impeller blades poses a unique challenge due to the sharp leading and trailing edges with curved airfoils, causing a shadowing effect during coating deposition. This can lead to non-uniform coating at sharp edges, resulting in spallation caused by high residual stress. To address this challenge, we employed various strategies, including a specially designed fixture providing two-axial rotation to the impeller, the incorporation of masking fingers to mitigate high coating deposition rates at sharp edges, modification of the ion cleaning process to enhance coating adhesion, and adjustments to chamber conditions such as increased working pressure using a mixture of N2 and Ar gases while reducing the substrate bias voltage to reduce coating residual stress.

The TiCrN coating, applied to a stainless-steel impeller and flat coupons by using cathodic arc deposition, underwent comprehensive characterization and testing. The coated impeller exhibited excellent surface coverage without spallation or cracking. The TiCrN-coated blades displayed consistent chemical compositions, and the surface roughness values (Ra) were maintained below 0.7 µm. The average hardness value of the coating was 2204 HV. The coating had excellent coating/substrate adhesion strength with critical loads higher than 40 N. Compared to the uncoated 1Cr11Ni2W2MoV substrate alloy, the TiCrN-coated blades demonstrated more than two times improvement in erosion resistance at 30°, 60° and 90° impingement angles. Furthermore, the TiCrN-coated samples exhibited no signs of corrosion damage after exposure to salt fog for 60 hours. In conclusion, the TiCrN coating applied to the stainless-steel substrate demonstrated exceptional performance in terms of erosion resistance, highlighting its potential for use in protecting turbine engineer impellers in aircraft engines.

4:00pm **IA2-2-TuA-8 Next Generation of Compositions & Coatings for Netzero & Sustainable Aviation***, **Tanvir Hussain (tanvir.hussain@nottingham.ac.uk)**,* University of Nottingham, UK **INVITED**

Thermal spray has proven to be a versatile coating deposition technique for many materials for wear, corrosion and thermal barrier applications; however, it is still challenging to spray oxygen-sensitive nano materials or carbides which sublimate in thermal spray.

Here we present a summary of various new approaches to deposit graphene nanoplatelet coatings and carbon nanotubes on their own from suspension and powder, as well as pre-mixed powders and composite suspension thermal spray. The new hardware modification and feedstock development allow direct incorporation of carbon-based nanomaterials into the thermal sprayed coatings that allow improvement in performance (for example, over two orders of magnitude in wear). Similarly, SiC is a cheap, abundant material for many engineering applications, including wear, but their lack of melting in a plasma or combustion flame in a desirable manner makes it very challenging to turn these into coatings. Here, we have developed a suspension and solution precursor process, a one-step route to produce composite coatings where SiC comes from suspension and the precursor salts (yttrium aluminium garnet here) transform into a protective matrix in the coating. This one-step process of suspension and solution precursor thermal spray has the potential to transform the materials portfolio of thermal sprayable materials.

Finally, axial injection suspension plasma sprayed coatings with columnar microstructures from 'non-flammable' organic solvent-based Yttria Stabilized Zirconia (YSZ) suspension will be introduced. The talk will cover the consequences of CMAS infiltration into these new coatings. The degradation of the coating mechanical properties due to CMAS ingression will be reported along with residual stresses using Raman spectroscopy. The common thread through all these examples will be reducing our CO2 footprint and improving component lifetime to achieve towards a netzero aviation.

4:40pm **IA2-2-TuA-10 Improved High Temperature Tribology for Aero-Engine Components by PVD Coatings***, **A.O. M. Eriksson (anders.o.eriksson@oerlikon.com)**,* Oerlikon Balzers, Oerlikon Surface Solution AG, Liechtenstein*; T. Middlemiss,* Oerlikon Balzers Coating UK Ltd., UK*; C. Jerg, E. Vaziri Beiraghdar, P. Kaller,* Oerlikon Balzers, Oerlikon Surface Solution AG, Liechtenstein*; T. Stelzig,* Oerlikon Balzers Coating Germany GmbH, Germany*; J. Ramm,* Oerlikon Balzers, Oerlikon Surface Solution AG, Liechtenstein

Aero engines operate under aggressive environments in which some of their components are exposed to temperatures well above 600°C. Under these conditions fretting and sliding wear is a major concern. For thermal management, dedicated materials like single crystal superalloys or Titanium aluminides are used in combination with protective coatings such as thermal barrier coatings and environmental barrier coatings. Besides thermal management, tribological behavior is important for engine components, such as shrouds, mechanical seals, rings, or joints, which are in contact with counterparts. Relative motion caused by vibrations is a common reason for fretting or sliding wear of the surfaces in contact. Pits and grooves on the contacting surfaces, as well as debris of removed material, may result in crack initiation and in failure of the component. Because the service temperatures are well above the application area for standard carbon-based tribological coatings, we have explored PVD coatings of oxides and nitrides. Coatings have been applied on superalloy specimens and tested in reciprocal sliding motion against superalloy counterparts at temperature of about 700 °C. The PVD coatings significantly reduced wear of the coated specimens, in contrast to extensive wear in the pairing of uncoated superalloy specimen with uncoated superalloy counterpart. Moreover, the evolution of the friction coefficient through the reciprocal sliding test was evaluated, where the coated specimen quickly stabilized at a constant value as opposed to the uncoated test conditions. The stable wear conditions are attributed to a tribologically transformed layer which was observed on the surface of the coatings, comprising components of the coating and superalloy material of the counterpart. The coatings can thus help to enhance lifetime and performance of tribologically loaded high-temperature components.

5:00pm **IA2-2-TuA-11 Development of Environmentally Friendly Solid Carburizing for Improving Fatigue Properties of AISI 4118 Steel**, ***Tomofumi Aoki (ao.tomofumi@keio.jp)**, D. Kasai,* Graduate School of Science and Technology, Keio University, Japan*; M. Hayama,* Keio University, Japan*; S. Takesue,* Kyoto Institute of Technology, Japan*; M. Tsukahara, Y. Misaka,* Neturen Co., Ltd., Japan*; J. Komotori,* Keio University, Japan

Gas carburizing is used extensively in the industry to improve the fatigue properties and the wear resistance of steel. However, the process is time-consuming and emits large amounts of gases, such as CO_2. Thus, we focused on atmospheric-controlled induction heating fine-particle peening (AIH-FPP) to resolve these challenges.

AIH-FPP combines induction heating and fine-particle peening. Shot media was projected onto a specimen heated with an IH coil. In AIH-FPP, when carbon is used as the projection media and steel is used as the base material, carbon can diffuse into the steel, and carburizing can be achieved rapidly. We named this process environmentally friendly solid carburizing, as it controls CO_2 emission and lessens the environmental burden. Accordingly, the aim of this study is to improve the fatigue properties of steel in a reduced time using this process.

The material used in this study was SCM 420H (AISI 4118 or equivalent) and the steel was machined into hourglass-shaped specimens. The air in the chamber was replaced with N_2 gas. The specimens were heated to 1273K for 30 s and then held at the temperature for 60 s. While heating and maintaining the temperature, steel particles coated with carbon were projected. The specimens were then cooled with N_2 gas. Afterward, these were requenched. We also prepared conventional gas carburized specimens.

An electron probe micro analyzer (EPMA) was employed to analyze the distribution of carbon concentration. The microhardness of each specimen was examined on their longitudinal section using a micro Vickers hardness tester. The fatigue test was conducted under axial loading with the stress ratio of -1 at room temperature, and test frequency of 10 Hz.

Environmentally friendly solid carburizing process diffused carbon up to 300 µm from the specimen surface and increased the carbon content on the specimen surface to approximately 0.5 mass%. No significant decrease in hardness was observed in the vicinity of the specimen surface. This result suggests that grain-boundary oxidation did not occur. This is because of the extremely low O_2 present in the treatment chamber, indicating that no CO was produced during the treatment. In addition, we consider that C_2H_2 is not produced during the treatment due to the displacement of the air with N_2 gas in the chamber. These results strongly suggest that the carbon diffused in this process by a mechanism different from the conventional gas carburization.

The fatigue life at the stress amplitude of 700 MPa was approximately 10 times longer than that of a conventional gas carburized specimen. This is because of the higher hardness on the specimen surface.

Author Index

Bold page numbers indicate presenter