Coatings for Use at High Temperatures
Room Town & Country D - Session A2-1-TuA

Thermal and Environmental Barrier Coatings I

Moderators: Sabine Faulhaber, University of California, San Diego, USA, **Pantcho Stoyanov**, Concordia University, Canada

1:40pm **A2-1-TuA-1 Mechanisms of CMAS Attack on Aero-Engine Components***, Elisa Zaleski (elisa.zaleski@pw.utc.com),* Pratt & Whitney, USA **INVITED**

Gas turbine engines operating in hot, sandy environments ingest siliceous debris termed CMAS for calcium magnesium aluminosilicate (CMAS). This siliceous material deposits on the surface of hot section components leading to premature degradation of these materials. As engine temperatures rise, CMAS-induced failures accelerate, leading to the need for more robust, capable mitigation strategies. This talk will focus on the aspects and mechanisms of CMAS attack most relevant to gas turbine engines.

2:20pm **A2-1-TuA-3 A New Approach to Protect Thermal Barrier Coatings (TBCs) Using Air Plasma Spray (APS)/High-Velocity Oxygen Fuel (HVOF) Coating of Si_3N_4***, **Said Bakkar (sbakkar@udallas.edu)**, E. Zucha, J. Moldenhauer, E. Steinmiller,* University of Dallas, USA*; T. Hossain,* Ceriumlab , USA*; W. Flanagan,* University of Dallas, USA

Gas Turbine Engines (GTEs) operate at high temperatures, submersed in a high-density gas. Thermal barrier coatings (TBCs) are widely used to protect the engine superalloys from oxidation and other degradation. TBC is a compound of Yttrium stabilized zirconia (YSZ). These TBCs are vulnerable to Calcium–Magnesium–Alumino–Silicate (CMAS) deposits and volcanic ash penetration. A new approach of protecting the topcoat of the TBC from the infiltration of molten CMAS was explored using various thicknesses of silicon nitride Si_3N_4 to work as a sacrificial/Impermeable layer. The High-Velocity Oxygen Fuel (HVOF) and Air Plasma Spray (APS) coating techniques were used and the CMAS test was performed using torch and furnace techniques at 1250 °C. The blocked CMAS infiltration in this approach was investigated using XRD, SEM, TEM techniques.

2:40pm **A2-1-TuA-4 Development of a Low Power Plasma Reactor for the Local Deposition of YSZ Thermal Barrier Coatings at Atmospheric Pressure***, **Sandra Segondy (sandra.segondy@chimieparistech.psl.eu)**,* Chimie ParisTech, PSL Research University, CNRS, Institut de Recherche de Chimie Paris (IRCP), France*; C. Rio, S. Landais,* ONERA, DMAS, Université Paris-Saclay, France*; C. Guyon, F. Rousseau,* Chimie ParisTech, PSL Research University, CNRS, Institut de Recherche de Chimie Paris (IRCP), France

Repair methods are of great interest for the aeronautic industry, especially for gas turbines. Deposition techniques that can quickly and easily repair small and localized damaged areas of Thermal Barrier Coatings (TBCs) located on combustion chambers could be economically interesting. In a first approach, a Low-Power Plasma Reactor (LPPR) working at low pressure (< 1000 Pa, 240 W) and using solution precursors was tested to locally deposit performant Yttria Stabilized Zirconia (YSZ) as TBC. Highly porous TBCs exhibiting low thermal conductivity were deposited, however, vacuum conditions were difficult to implement at an industrial scale. For this reason, a new version of LPPR working at atmospheric pressure with solution precursors was investigated.

The plasma torch (AcXys Plasma Technologies) based on a non-thermal rotating arc technology was mounted on a 3-axis motorized table (**Fig. 1**). The plasma discharge was generated in the reactor by AC electrical power with a frequency of 80 kHz. Operating power ranged between 600 – 1000 W using air as the discharge gas (gas flow rate: 35 slpm). The precursors were composed of zirconium and yttrium salts in aqueous solution. The liquid precursors were injected (solution feed rate: 1 mL/min) in the plasma afterglow to be sprayed and deposited onto superalloy substrates (with or without a MCrAlY bond coat) to form a TBC. Because the afterglow temperature was colder than in the case of thermal spray processes (T < 1000 °C), the spray distance was lower than 10 mm. Therefore, the YSZ deposition could be done locally in hard-to-reach regions through this low power plasma.

FTIR analysis was used to evaluate the ratio of produced oxides over the remaining precursors. The coating microstructural characteristics and the porosity were assessed by SEM observations. The composition and crystalline structure were determined by EDX and XRD respectively. The YSZ coatings exhibited the expected stoichiometry, a precursor conversion of 98 mol%, a tetragonal structure (**Fig. 2**), a good adherence to the substrate and a porosity evaluated around 30 vol%. In addition, the thickness of the YSZ coating could be higher than 100 µm in less than 1 hour (**Fig. 3**). The coating morphology seemed to exhibit two different microstructures depending on the deposition conditions: a more porous morphology closer to a columnar structure and a denser and granular microstructure (**Fig. 4**). The impact of the coating deposition conditions explaining these two different microstructures is currently under investigation.

3:00pm **A2-1-TuA-5 Oxidation Behaviour and Mechanical Properties of Sputter-Deposited $TMSi_2$ Coatings (TM = Mo, Nb, Ta)***, **Ahmed Bahr (ahmed.bahr@tuwien.ac.at)**,* Christian Doppler Laboratory for Surface Engineering of high-performance Components, TU Wien, Austria*; S. Richter, T. Glechner, T. Wojcik,* Christian Doppler Laboratory for Surface Engineering of high-performance Components, TU Wien , Austria*; J. Ramm,* Oerlikon Surface Solutions AG, Liechtenstein*; O. Hunold,* Oerlikon Surface Solutions AG , Liechtenstein*; S. Kolozsvári,* Plansee Composite Materials GmbH , Germany*; H. Riedl,* Christian Doppler Laboratory for Surface Engineering of high-performance Components, TU Wien, Austria

High temperature environments not only involve materials with excellent creep properties, but also highest oxidation resistance and chemical inertness. Transition-metal disilicides ($TMSi_2$) based thin films are suggested as promising candidates for novel protective coating materials used in various high temperature applications. $TMSi_2$ exhibit an attractive mix of highest phase stability, reasonable mechanical properties and outstanding oxidation resistance.

In this study, we investigated the role of Si on the phase formation and oxidation kinetics of sputter-deposited $TMSi_2$ (TM = Mo, Ta, Nb) films. The coatings were analyzed in terms of chemical composition, phase constitution, and mechanical properties (i.e. H and K_{IC}) using diverse high-resolution characterization techniques. Moreover, the oxidation kinetics were systematically studied for all three systems at different temperature regimes up to 1400 °C. These analyses were supported by a detailed structural and morphological characterization of oxide scales formed.

4:00pm **A2-1-TuA-8 New Hydrogen Barrier Coatings***, **Akram ALHUSSEIN (akram.alhussein@utt.fr)**, I. LAKDHAR,* University of Technology of Troyes , France*; J. CREUS,* La Rochelle University , France

The interaction of hydrogen with different metallic materials was reported and discussed in the literature. It has been found that hydrogen affects significantly the mechanical properties. This smallest chemical element penetrates into the metallic structure and reduces its ductility and loading capacity [1].

Coatings present a great solution to protect a material and give it multifunctional properties. Coatings are widely considered as a good solution to design hydrogen barriers in order to trap the adsorbed hydrogen and avoid its diffusion towards the substrate through the interface.

The objective of our work is the development of new generation of hydrogen barrier coatings to protect metallic components used in hydrogen atmosphere. After three years of working on this research project, we successfully developed a new AlTiW thin film deposited by magnetron sputtering technique [2]. The deposition rate was controlled to obtain 4 µm as an uniform film thickness.

The functional properties of coating such as corrosion properties and thermal stability as well as its protective performance for steels in a hydrogen environment were investigated. The influence of tungsten content on the microstructure, thermal stability, mechanical properties, corrosion resistance and hydrogen permeation inhibition of the coating was analyzed.

XRD, DSC and TEM analyses were carried out to check the amorphous state of the coating and to determine the glass transition and crystallization temperatures. These later were increased with the increase of W concentration up to 17 at%. On the other side, the corrosion resistance in a saline solution was decreased. The addition of W led to increase the coating mechanical properties (hardness and Young's modulus).

Chemical and electrochemical hydrogen charging methods were carried out to expose coated steels to hydrogen. The tungsten incorporation in the binary AlTi coatings highly improved their resistance to hydrogen absorption. The results obtained confirm that the $Al_{45}Ti_{38}W_{17}$ coating presents the best hydrogen barrier behavior.

In the near future, we will focus on the enhancement of the coating efficiency and the development of other nanostructured coatings for using in different real conditions.

References:

[1] A. Alhussein, J. Capelle, J. Gilgert, S. Dominiak, Z. Azari, Int J Hydrogen Energy 36 (2011) 2291.

[2] I. Lakdhar, A. Alhussein, J. Capelle, J. Creus, Applied Surface Science 567 (2021) 150786.

4:20pm **A2-1-TuA-9 Dual–Layer PVD Coating System With Integrated Diffusion Barrier for Oxidation Protection of γ–Tial Based Alloys***, Peter-Philipp Bauer (peter-philipp.bauer@dlr.de),* German Aerospace Center, Germany*; R. Swadźba,* Łukasiewicz Research Network - Institute for Ferrous Metallurgy, Poland*; L. Klamann, N. Laska,* German Aerospace Center, Germany

Titanium aluminides are used as structural materials for turbine blades in jet engines due to their low density and the resulting weight reduction. However, their application is limited to service temperatures below 800 °C due to insufficient oxidation resistance. A feasible way to increase the service temperature is the application of Al-rich oxidation protective coatings to ensure the formation of a thermally grown alumina layer. Nevertheless, interdiffusion processes, especially of Al, between the intermetallic coatings and the TiAl-based substrate materials have detrimental effects on the coating as well as on the substrate alloy. Therefore, the interdiffusion processes should be suppressed or at least reduced.

In the present work, the properties of a 1 µm thick layer of the Ti_5Si_3 phase as a potential diffusion barrier for an afterwards applied oxidation resistant Al–Ti coating was investigated. For this purpose, DC magnetron sputtering was used to deposit a coating of partially crystalline Ti_5Si_3 phase prior to the deposition of an Al_2O_3 forming Al-30Ti (in at.%) top layer. The deposition was performed as a one-batch process in an industrial scale multisource sputter coater. This allowed depositing the Ti_5Si_3 interlayer from pure Ti and Si targets. Afterwards, the Al-30Ti top layer was deposited in the same sputter process by changing the substrate position and using Ti and Al targets.

Cyclic oxidation tests at 900 °C for 1000 cycles (1 h each) combined with thermogravimetric analysis were performed in laboratory air in order to study the oxidation behavior of the coating systems. The morphologies of the coating systems and the microstructural development during the oxidation tests were investigated by scanning electron microscopy and high-resolution transmission electron microscopy. The intermetallic phases and the phase evolution were monitored by in–situ high temperature x-ray diffraction as well as standard x–ray diffraction.

The results show that the Ti_5Si_3 phase could effectively slow down the Al depletion in the Al-30Ti at.% coating due to minor Al inwards diffusion into the γ–TiAl substrates. As a result, the dual–layer coating system provided a high oxidation resistance due to the long-term stable formation of thermally grown alumina on the surface. The stability of the interlayer of the Ti_5Si_3 phase was excellent and it was still present even after 1000 1-h-cycles of oxidation at 900 °C without any changes in thickness. In contrast, the single layer coating of Al-30Ti suffered from breakaway oxidation after already 800 cycles of exposure to 900°C in air.

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