Coatings for Use at High Temperatures
Room Pacific Salon 2 - Session A2-2-ThA

Thermal and Environmental Barrier Coatings II

Moderators: Sabine Faulhaber, University of California, San Diego, USA, **Kang N. Lee**, NASA Glenn Research Center, USA, **Pantcho Stoyanov**, Pratt & Whitney, USA

1:20pm **A2-2-ThA-1 Design of Multiphase Environmental Barrier Coatings: Toward Multifunctional Molten Deposit Resistance**, ***David Poerschke,*** University of Minnesota, USA **INVITED**

The ceramic thermal and environmental barrier coatings (T/EBC) employed to protect SiC-based composited in gas turbine engines must satisfy multiple interrelated performance requirements including phase stability, tolerance to thermal strains, and resistance to environmental degradation (e.g., via molten deposits or foreign object impact). It is increasingly evident that rare earth disilicate coatings, which offer good phase stability and minimize the coefficient of thermal expansion (CTE) mismatch with SiC, are not sufficiently resistant to degradation caused by silicate deposits. Reactions between the coatings and deposits progressively consume the coating and produce phases with increased CTE mismatch. Upon thermal cycling, the penetration of channel cracks originating in the reaction layer through the remaining coating and into the composite accelerates the failure of both the coating and the underlying component. Due to the limited number of materials satisfying all of the design requirements, achieving improved performance likely requires multiphase coating systems. This presentation presents a multi-pronged approach to new develop new coating materials. The effort combines new understanding of the thermochemistry of the coating-deposit interactions in order to identify material combinations that minimize the coating recession depth upon exposure to various deposits while developing composite materials with precisely tunes CTEs to manage thermal strains over a wide range of operating conditions.

2:00pm **A2-2-ThA-3 Comparison of Oxidation Procedures of MCrAlY Coatings Deposited by PVD Cathodic Arc Evaporation**, *X Maeder, J Ast,* Empa - Swiss Federal Laboratories for Materials Science and Technology, Switzerland*; M Polyakov,* EMPA - Swiss Federal Laboratories for Materials Science and Technology, Switzerland*; M Döbeli,* ETH Zürich, Switzerland*; A Neels, A Dommann,* Empa - Swiss Federal Laboratories for Materials Science and Technology, Switzerland*; B Widrig,* ***Oliver Hunold****, J Ramm,* Oerlikon Balzers, Oerlikon Surface Solutions AG, Liechtenstein

Development of superalloys which can sustain higher operating temperatures is necessary to increase efficiency of land-based and areo turbines. This requires enhanced surface stability of the components with respect to oxidation and corrosion. The coatings applied to superalloys substrates need therefore to form a well adherent and stable interface towards the substrate by diffusion process and create a protective oxide at their surface. We will show here the capability of depositing MCrAlY coatings by cathodic arc evaporation on Ni-based superalloy substrates. MCrAlY targets where produced by spark plasma sintering and processed in non-reactive mode and in mix non-reactive and reactive modes on directional solidified CM247 and single crystalline PWA1483 substrates. The phases, microstructure and composition of the targets and synthesized coatings are characterized by TEM, transmission EBSD, X-ray diffraction and RBS analyses and discussed. The interface between the MCrAlY coatings and the different Ni-based superalloy substrates before and after annealing is investigated and different approaches to form an oxide scale on top of the MCrAlY coating are discussed.

2:20pm **A2-2-ThA-4 Effect of APS Flash Bond Coatings and Curvature on Furnace Cycle Lifetime of Rods**, ***Michael Lance****, J Haynes, B Pint,* Oak Ridge National Laboratory, USA*; E Gildersleeve, S Sampath,* Stony Brook University, USA

The addition of an air plasma sprayed (APS) “flash” bond coating layer on top of a high velocity oxy-fuel (HVOF) bond coating significantly extended the lifetime of APS yttria stabilized zirconia (YSZ) top coatings on rod specimens of superalloy 247 tested using 100-h cycles in air+10%H_2O at 1100°C. The flash coatings of both NiCoCrAlY and NiCoCrAlYHfSi powder were compared to an HVOF-only and a vacuum plasma sprayed (VPS) NiCoCrAlYHfSi bond coating. The flash coatings appear to form a mixed oxide-metal zone that appeared to inhibit crack formation and extend lifetime compared to conventional bond coatings. The underlying HVOF layer acted as a source of Al for this intermixed zone and prevented the oxide from penetrating deeper. Residual stress in the thermally grown Al_2O_3 scale was measured using photo-luminescence piezospectroscopy (PLPS) as a function of time for each coating variation, including a comparison of concave and convex surfaces.

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2:40pm **A2-2-ThA-5 Investigation of Thermally Grown Oxide Stress in Plasma-spray Physical Vapor Deposition and Electron-beam Physical Vapor Deposition Thermal Barrier Coatings via Photoluminescence Spectroscopy**, ***Linda Rossmann****, M Northam,* University of Central Florida, USA*; V Viswanathan,* Praxair Surface Technologies, USA*; B Harder,* NASA Glenn Research Center, USA*; S Raghavan,* University of Central Florida, USA

Gas turbine engines for aircraft propulsion require thermal barrier coatings (TBCs) to protect metallic components in the hot section from the extreme temperatures of operation, which may exceed 1200 °C. These coatings are typically 6-8% yttria-stabilized zirconia (YSZ), and the standard methods of coating deposition are air plasma spray (APS) and electron-beam physical vapor deposition (EB-PVD). EB-PVD produces a higher-quality coating than APS due to its resulting columnar microstructure that increases the strain tolerance of the coating. Plasma-spray physical vapor deposition (PS-PVD) is a promising technique that offers several advantages over EB-PVD, including lower cost, shorter coating time, customizability of microstructure by varying processing parameters, and possibility of non-line-of-sight coating. However, the effect of this process on the resulting microstructure, properties, and performance is not fully understood. In this work, TBCs manufactured by both EB-PVD and PS-PVD were investigated via photoluminescence spectroscopy after varying amounts of thermal cycling, to investigate the effect of deposition process on the stress state of the thermally grown oxide (TGO) layer.

This work investigates the residual stress in the TGO of samples made by EB-PVD and PS-PVD, thermally cycled in the same way at multiple lifetimes (as-deposited, 300 cycles, and 600 cycles), to evaluate the effects of deposition method. As-deposited PS-PVD samples were given a 1-hour heat treatment, during which they developed a TGO. This was found to be in compression on the order of 2-3 GPa, consistent with published data on EB-PVD TBCs. Other PS-PVD samples were cycled for 300 and 600 hours, and these exhibited stress relaxation compared to the 1-h heat treated, suggesting some stress relief from damage. The findings from these investigations will be presented in the paper.

In this study, we compare the TGO residual stress evolution in PS-PVD and EB-PVD TBCs to shed light on their respective responses to thermal cycling. These results contribute to understanding how the PS-PVD process compares to the EB-PVD process with respect to coating life and durability.

3:00pm **A2-2-ThA-6 Thermally Conductive and Electrically Insulating Epoxy Nanocomposites with Intercalation of Aluminum Nitride Nanoparticles into Exfoliated Graphite**, ***Che Juei Wu***, National Cheng Kung University, Taiwan

In this study, the enhancement of thermal conductive of epoxy-based nanocomposites without scarifying electrical insulating were demonstrated. This was done by introducing intercalated aluminum nitride (AlN) into expanded graphite in the nanocomposite. Intercalation of AlN nanoparticles into adjacent exfoliated graphite were firstly prepared via solution mixing with supercritical fluid CO_2 ($SCCO_2$). $SCCO_2$ ‘s low surface tension and viscosity lead to greater penetration into porous solid. Epoxy composites with an intercalated of AlN nanoparticles into exfoliated graphite were fabricated using a three roll mills machine. Scanning electron microscopy images reveal that intercalation of AlN into exfoliated graphite structures were formed and were uniformly dispersed in the epoxy matrix. The in-plane and through-plane electrical and thermal conductivities of thin thermal interface layers of epoxy composites were discussed. Compare to epoxy composites with only exfoliated graphite, epoxy composites with intercalation of AlN nanoparticles into exfoliated graphite not only maintain epoxy’s electrically insulation but also enhance through-plane thermal conductivity, which make this material an attractive candidate for electronic field applications especially thermal interface materials (TIMs).

3:20pm **A2-2-ThA-7 Effect of Feedstock Species on Thermal Durability of Thermal Barrier Coatings**, ***Sangwon Myoung****, B Yang, I Kim,* Doosan Heavy Industries and Construction, Republic of Korea*; Y Jung,* Changwon National University, Republic of Korea

Thermal durability and stability of thermal barrier coatings (TBCs) are closely related with its microstructure and feedstock species. Numerous factors, besides the thermal and mechanical properties, have to be considered in practical applications of TBCs. There is therefore a need to the reliability and lifetime performance of the plasma sprayed TBC system.

In this study, the microstructures in the top and bond coats of TBCs have been deposited different plasma spray process. The TBC system with the thicknesses of 500 and 200 mm in the top and bond coats, respectively, were prepared with the air plasma sprayed (APS) coating system using ZrO_2–8wt% Y_2O_3 powders for the top coats and vacuum-plasma sprayed coating system using Ni-based metallic powders for the bond coats . In order to investigate the improvement of thermal durability, the furnace cyclic test (FCT) was performed for the TBC samples at a temperature of 1100°C with a dwell time of 1 h for 1000 cycles. Porosity and pore size distribution were measured with the FCT, and the effects of feedstock species in the TBC on mechanical properties such as hardness and toughness were observed, including the adhesive strength before and after the FCT. The nominal pore size of as-prepared TBC system is dramatically reduced with increasing thermal exposed cycle. The harness and toughness values are increased to 1000 cycles. The influence of feedstock species on the microstructural evolution and thermal durability of TBC is discussed.

3:40pm **A2-2-ThA-8 Development of Environmental Barrier Coatings for SiC/SiC Ceramic Matrix Composites via CVD***, **Till König**, M Galetz,*
DECHEMA-Forschungsinstitut, Germany

With increasing combustion temperature of turbine engines the commonly used nickel-based superalloys are getting closer to their melting point and excessive cooling along with thermal barrier coatings are used to maintain the properties at the desired level. The substitution of these alloys by Ceramic Matrix Composites (CMC) for applications in the high temperature region of turbines is widely discussed and first parts are in service. Due to their mechanical properties at high temperatures especially SiC/SiC-CMC are investigated. Their advantages include a low density, high specific strength and a low creep rate even at very high temperatures. Therefore the efficiency of the turbines can be increased by using higher combustion temperatures, the abandonment of cooling and reducing the mass. In oxidizing atmospheres these materials form silica scales, which are generally considered protective. But the presence of water vapor, which forms during the combustion process, results in the volatilization of the silica scale by the formation of hydroxides. The simultaneous process of oxidation and evaporation follows paralinear kinetics and makes it necessary to apply coatings that reduce the evaporation and result at best in parabolic kinetics. Under investigation are multi layered environmental barrier coatings (EBC) that reduce the silica activity by mixed oxides (e.g. rare earth silicates) or by forming oxides not prone to evaporation (e.g. Al_2O_3).

In this study the chemical vapor deposition process (CVD) was used instead of or in addition to the commonly used thermal spraying with the aim to apply coatings that show a better adherence and cover the whole surface (line of sight). A layered chromium aluminide, chromium silicide coating was applied by chromizing and subsequent aluminizing in a second step, both via pack cementation. Aluminum nitride was applied by a two-step process consisting of aluminizing via pack cementation and subsequent nitriding as well as by direct deposition via high temperature CVD. The evaporation of these coatings was tested in comparison to the uncoated CMC in water vapor containing atmospheres. The adherence was investigated in synthetic air under thermal cycling conditions to test the influence of possible thermal expansion mismatches. To identify the phases and the microstructure X-ray diffraction (XRD), scanning electron microscope (SEM) and electron probe microanalysis (EPMA) were used.

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