Coatings for Use at High Temperatures
Room Grand Hall - Session AP-ThP

Coatings for Use at High Temperatures (Symposium A) Poster Session

AP-ThP-2 High Temperature Performance of CrAlN Coating on Stainless Steel Substrates in Simulated Diesel Exhaust Environment, *S Yang,* Miba Coating Group. Teer Coatings Ltd., UK*; V Vishnyakov,* Institute for Materials Science, University of Huddersfield, UK*; P Navabpour,* Miba Coating Group. Teer Coatings Ltd., UK*; J Allport,* Institute for Materials Science, University of Huddersfield, UK*; **Hai Lin Sun**,* Miba Coating Group. Teer Coatings Ltd., UK

CrAlN coatings on stainless steels were subjected to temperature cycling up to 750 ^{0}C in air, simulated diesel engine exhaust composition and actual diesel engine exhaust. Scanning electron microscopy (SEM), X-ray diffraction (XRD) and glow discharge optical emission spectrometry (GDOES) were used to study the surface morphology, phase microstructures and composition coating depth profiles. It was found that high temperature corrosion on the coating surface induced formation of passive oxides, which provided a barrier function to further corrosion. The microstructure of the coatings did not change significantly in ambient air at temperature of 750 ℃ . The results show that CrAlN coatings have high hardness, thermal stability, corrosion and erosion resistance. The coatings have potential for applications to protect surface of mechanical components in diesel exhaust systems.

Key words: Thermal stability, high temperature, oxidation, corrosion, erosion.

AP-ThP-3 e-Poster Presentation: Improvement of the Robustness of Time to Failure Assessment in Tbc System, *M Theveneau, B Marchand, V Guipont,* Mines ParisTech, PSL Research University, MAT - Centre des Matériaux, France*; F Coudon,* SAFRAN Tech, France*; **Vincent Maurel**,* Mines ParisTech, PSL Research University, MAT - Centre des Matériaux, France

One of the major challenges for TBC system is to determine the time to failure of ceramic layer during ageing. The aim of this paper is to propose new methodologies for both experimental assessment of adhesion and for analyzing the robustness of model of lifetime to spallation.

Recently, the use of LAser Shock Adhesion Test (LASAT) has shown its capability for both ranking different coating solutions and evaluating the evolution of a given coating as a function of aging [1-2]. The methodology developed in this study is based on the evaluation of interfacial crack propagation from a defect introduced by laser shock, an interfacial delaminated area, known in size and location. The evolution of interfacial delamination during thermal cycling was shown to be consistent with measured interfacial delamination measured by cross-sectioning. Thus, the influence of dwell time at high temperature has been clearly established, confirming that short dwell time was very detrimental as compared to long dwell at high temperature [3-4]. Moreover, this new method has shown a very small scatter as compared to other adhesion testing [2].

On the other hand, some lifetime to spallation models have been tested, focusing on two mains aspects. Firstly, the ability of existing models to reproduce the influence of loading parameters has been tested (e.g. the influence of dwell time at high temperature or the influence of maximum temperature) [3-5]. Secondly, the robustness of this kind of models has been analyzed through sensitivity analysis based on large numerical sampling. As a conclusion, the propagation of scatter from measurement to life modeling has been evaluated and guidelines for experimental focus points have been derived.

References

[1] Guipont, et al (2010). Journal of Biomedical Materials Research Part A, 95(4), 1096-1104.

[2] Guipont, et al. "Interfacial toughness evolution under thermal cycling by laser shock and mechanical testing of an EB-PVD coating system." (2018). http://dc.engconfintl.org/cgi/viewcontent.cgi?article=1033&context=tbcv

[3] Courcier, C et al (2011). Interfacial damage based life model for EB-PVD thermal barrier coating. Surface and Coatings Technology, 205(13-14), 3763-3773.

[4] Soulignac, Romain, et al. "Cohesive zone modelling of thermal barrier coatings interfacial properties based on three-dimensional observations and mechanical testing." Surface and Coatings Technology 237 (2013): 95-104.

[5] Chaboche, J. L., et al "Lifetime assessment tools for thermal barrier systems" in "Thermal Barrier Coatings IV",Eds, ECI Symposium Series, (2015). http://dc.engconfintl.org/thermal_barrier_iv/34

AP-ThP-5 Wear Resistance Performance of AlCrN and TiAlN Coated H13 Tools during Friction Stir Welding of A2124/SiC Composite, ***Akeem Adesina**, F Al-Badour, Z Gasem,* King Fahd University of Petroleum and Minerals, Saudi Arabia

Tool wear during friction stir welding (FSW) of hard particulate reinforced aluminum metal matrix composites

(Al MMCs) are more prominent due to the tool interaction with the particulates at high strain rate. Considering

the excellent mechanical and wear resistance properties of cathodic arc PVD coatings, they are expected to abate

the wear of tools during FSW of Al MMCs. Hence, it is the aim of this study to investigate the contribution of

cathodic arc PVD deposited AlCrN and TiAlN coatings in alleviating tool wear during FSW of Al MMCs. AlCrN

and TiAlN coated H13 FSW tools were used to butt weld 8 mm thick aluminum alloy 2124 reinforced with 17 vol

% SiC of 3 µm particle size. Interestingly, the coated tools exhibited significant improvement in wear resistance

of about 92 and 80%, respectively, over the bare H13 tool. Over 97% reduction in the wear of the FSW tool was

recorded during the plunging stage with the use of the coated tools. Additionally, AlCrN and TiAlN coated tools

considerably improved the surface finish of the welded Al MMC. The coated tools demonstrated superior wear

resistance due to the improved scratch crack resistance, high mechanical and oxidation resistance properties of

the coatings. Dominant wear mechanisms on AlCrN and TiAlN coated tools were abrasive erosion and chipping

off by sharp and hard SiC particles while severe striation and oxidation characterized the wear mechanism of the

bare tool. The use of these coatings did not deteriorate the weld properties, rather somewhat improvement in the

hardness of the nugget zone was observed due to the characteristic dynamic stirring and refinement of the Al

matrix and SiC particles.

AP-ThP-6 Diffusion Model for Estimating the Iron Boride Layer Thicknesses, ***Oscar Armando Gómez-Vargas**,* Instituto Tecnológico de Tlalnepantla, México*; M Ortiz-Domínguez,* Universidad Autónoma del Estado de Hidalgo, México*; J Solis-Romero,* Instituto Tecnológico de Tlalnepantla, México*; M Flores-Rentería, I Morgado-Gonzalez, E Cardoso-Legorreta,* Universidad Autónoma del Estado de Hidalgo, México*; M Elias-Espinosa,* Tecnológico de Monterrey, México*; A Cruz Avilés,* Universidad Autónoma del Estado de Hidalgo, México

Surface hardening, a process that includes a wide variety of techniques (Carburizing, Nitriding, Nitrocarburizing, Boriding, and Thermal diffusion process), is used to improve the wear resistance of parts without affecting the more soft, tough interior of the part. In particular, resistant layers of borides are produced in ferrous and no-ferrous materials though the well-developed process of boriding. In the present work, the AISI 9840 steel was pack-borided in the temperature range 1123-1273 K for 2- 8 h to form a compact layer of Fe_2B at the material surface. A recent kinetic approach, based on the integral method, was proposed to estimate the boron diffusion coefficients in the Fe_2B layers formed on AISI 9840 steel in the temperature range 1123-1273 K. In the present model, the boron profile concentration in the Fe_2B layer is described by a polynomial form based on the Goodman's method. As a main result, the value of activation energy for boron diffusion in AISI 9840 steel was estimated as 193.08 $kJmol^{-1}$ by the integral method and compared with the values available in the literature. Three extra boriding conditions were used to extend the validity of the kinetic model based on the integral method as well as other diffusion models. An experimental validation was made by comparing the values of Fe_2B layers' thicknesses with those predicted by different diffusion models. Finally, an iso-thickness diagram was proposed for describing the evolution of Fe_2B layer thickness as a function of boriding parameters.

AP-ThP-7 STEM Investigations of Oxide Scales formed during Pre-oxidation of γ-TiAl, ***Radoslaw Swadzba,*** Institute for Ferrous Metallurgy, Poland

The paper presents results of pre-oxidation experiments of ɣ-TiAl alloy with Si-modified aluminide coatings intended for application as bondcoatings for Thermal Barrier Coatings. The goal of this work was to provide insight into the effect of different oxidation atmospheres and temperatures on the initial stages of oxide scale formation on bare and coated ɣ-TiAl. It is assumed that the formation of a thin (several hundreds of nanometers) and slow growing TGO consisting of α-alumina will enhance the adherence and lifetime of the TBCs on ɣ-TiAl.

The coatings were produced by pack cementation method applying a mixture consisting of Si and Al-containing powders and NH_4Cl activator. The additional surface modification by pre-oxidation under various atmospheres was performed to foster the formation of oxide scales characterized by various thicknesses as well as phase and chemical compositions. The pre-oxidation experiments were performed in various gases including a mixture of Ar and O_2 (from 0.01 to 10 %) as well as pure O_2 at 900 °C for 0.5, 2 and 4 hours. After the pre-oxidation experiments systematic studies were performed using Scanning Transmission Electron Microscopy (STEM) method in order to characterize the phenomena at the metal-scale interface and study the phase and chemical compositions as well as the microstructures of the formed oxide scales.

AP-ThP-9 Microstructure of MCrAlY Coatings Deposited Using HVOF after Heat Treatment and Aluminizing, *L Swadzba,* ***Aleksander Iwaniak,*** *R Swadzba, B Witala, B Mendala,* Silesian University of Technology, Poland*; G Wieclaw, P Lubaszka,* Certech Sp. z o.o., Poland

Effective oxidation and corrosion protection of turbine blades in aircraft engines used at high temperature in the atmosphere of exhaust gases is still a major technological challenge and is the subject of intensive research. In this work, the microstructure of coatings deposited on Inconel 738 alloy used for turbine blades was investigated. In the first stage of the research work MCrAlYHfSi (M=Ni) coatings made of Amperit 405.001 material with granulation +22-45 µm were deposited using HVOF method. The coatings were applied with variable process parameters by HVOF method using the Thermico system and the CJS K5.2-N burner. Then thermal treatment of the sprayed coatings was performed at 1050°C for 4 hours in argon atmosphere. After the heat treatment vapor phase aluminizing using the "out-of-pack" method was carried out at 1050°C for 5 hours. After each treatment thickness of the coatings was measured, the microstructures were investigated using SEM and chemical composition analysis (EDS) and their surface topography and roughness were determined using 3D profilometry.

AP-ThP-10 Effect of Vanadium Content on the High-temperature Tribo-mechanical Properties of Cr-Al-V-N Coatings Deposited by DC UBMS, *H Kim,* ***In-Wook Park,*** Korea Institute of Industrial Technology (KITECH), Republic of Korea

Quaternary Cr-Al-V-N coatings with vanadium content ranging from 0 to 13 at.% were deposited on WC-Co alloy substrates by an d.c. unbalanced magnetron sputtering using Cr-Al composite targets and pure vanadium target in an $N_2/(Ar+N_2)$ gas mixture for applications of the high-strength steel and aluminum alloys entails increasing demands on the surfaces of tools used for forming processes. The microstructure, mechanical, wear, tribological properties of the coatings were investigated by XRD, XPS, FESEM, HRTEM, surface 3D profiler, nano-indentation, scratch tester, and ball-on-disc tribo-meter. As the vanadium content increased, the nanohardness of the Cr-Al-V-N coatings showed higher hardness values (~30GPa) than that of CrAlN coating (~25GPa). Ball-on-disc tri-tests were used to assess the friction at 700°C, the friction coefficient of the Cr-Al-V-N coatings drastically decreased from 0.6 to 0.35 with increasing vanadium content up to 7 at.% in the coatings due to the formation of a tribolayer containing the lubricious oxide V_2O_5 as evidenced by XPS. Moreover, it was found that the improved friction coefficient and nanohardness with incorporated small amount of the vanadium contents contributed to excellent wear resistance of the coatings.

AP-ThP-11 Tensile Behavior of Air Plasma Spray MCrAlY Coatings: Role of High Temperature Aging and Process Defects, *C Cadet,* Mines ParisTech, PSL Research University, France*;* ***Thomas Straub,*** Fraunhofer Institute for Mechanics of Materials IWM, Germany*; D Texier,* Mines Albi, ISAE-SUPAERO, France*; C Eberl,* Fraunhofer Institute for Mechanics of Materials IWM, Germany*; V Maurel,* Mines ParisTech, PSL Research University, France

MCrAlY coatings are used as a protection layer against high temperature oxidation and corrosion for components working in an aggressive environment. In order to predict both coating and substrate lifetime, the characterization of thermomechanical properties of the coating is a challenging issue [1-3]. As these coatings are only a few hundreds of micrometers thick, their properties should be investigated with experimental tests adapted at this small scale [1-4].

In the present study, the mechanical properties of a free-standing MCrAlY coating and their evolution were scrutinized when it is aged in air for a large range of time and temperature. Free-standing micro-tensile specimens were prepared [1] and tested after different time/temperature ageing [4]. Based on digital image correlation to derive the strain evolution during loading, the stress-strain behavior has been identified. Thus a crucial effect of intrusive oxidation from deposition process defects and surface oxidation has been evidenced to drive both the ductility and the fracture mechanism of the tested material. For coarse intrusive oxidation, a loss of ductility has been identified, whereas metallic phase transformation (from b to g) increases the ductility of the material from 0.5 up to 3%. This composite effect will be analyzed through systematic microstructure and homogenization analyses. This methodology could be straightforward to determine the coupling between coating cracking and substrate failure under thermo-mechanical fatigue conditions [5].

References

[1] D. Texier, D. Monceau, J. C. Salabura, R. Mainguy, E. Andrieu, *Materials at High Temperatures*, 33 (2016) 325–337.

[2] D. Texier, D. Monceau, Z. Hervier, E. Andrieu, *Surface and Coatings Technology*, 307 (2017) 81–90

[3] Alam, M.Z., Satyanarayana, D.V.V., Chatterjee, D., Sarkar, R., Das, D. K., *Materials Science and Engineering: A*, 641 (2015) 84-95.

[4] Straub, T., Baumert, E.K., Eberl, C., Pierron, O.N., *Thin Solid Films*, 526 (2012) 176–182.

[5] Esin, V.A., Maurel, V., Breton, P., Köster, A., Selezneff, S., *Acta Materialia*, 105 (2016) 505–518.

AP-ThP-13 Influence of Si-Al Coating on Mechanical Properties of EBMed TiAl Alloy, ***Lukasz Pyclik,*** Avio Aero A GE Aviation Business, Poland*; L Swadzba, B Mendala, B Witala, J Tracz, R Swadzba,* Silesian University of Technology, Poland*; K Marugi,* Avio Aero A GE Aviation Business, Poland

The paper presents the results of investigations concerning the effect of silicon modified aluminide coatings on EBMed Ti-48Al-2Cr-2Nb (48-2-2) alloy. The study was performed on specimens machined from EBMed rods. The rods were printed by Avio Aero Cameri, Italy, and met heat treatment by hipping and solutioning. The specimens were manufactured by Silesian University of Technology, Poland, for coating or heat treatment. The anti-oxidation coating was applied on pre-machined specimens by a pack cementation process. The test results revealed difference between specimens in three conditions: bare, coated and heat treated corresponding to coating deposition process. The mechanical tests ensure environments as close as possible to current application in commercial novel engine, GE9X, where EBMed blades are applied on last stages of Low-Pressure Turbine designed by Avio Aero. All tests covered work at elevated temperatures at and above 1500F. All tests shown impact of coating on mechanical properties.

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