Coatings for Use at High Temperatures
Room Pacific E - Session A1-3-TuM

Coatings to Resist High-temperature Oxidation, Corrosion, and Fouling III

Moderators: Gustavo García-Martín, REP-Energy Solutions, Spain, **Justyna Kulczyk-Malecka**, Manchester Metropolitan University, UK

9:00am **A1-3-TuM-4 Protective Sol-Gel Coatings for Steels Against Corrosion of Molten Carbonates for Concentrated Solar Power Plants***,* ***Gustavo García Martín (gusgarci@ucm.es)****,* Universidad Complutense de Madrid, Spain*; T. de miguel Gamo,* Universidad Complutense de Madrid , Spain*; I. Lasanta Carrasco, M. Lambrecht, F. Pérez Trujillo, N. Garcia, C. Gómez de Castro,* Universidad Complutense de Madrid, Spain

In the last few years, the interest in renewable energies has suffered a significant increase, representing the Concentrated Solar Power (CSP) technology in the present and the future of the electric energy obtained from the sun on large scale. Commercial CSP plants usually use molten salt mixtures as thermal energy storage mediums. The currently used industrial compound is an alkali-nitrate mixture composed of 60 wt.% NaNO3/40 wt.% KNO3. However, the development of new molten salt mixtures with higher thermal stabilities that allow increasing the working temperature has received great interest in the last few years. In this respect, many authors have recently proposed the replacement of molten nitrate salts by molten carbonate salts, making possible an increase in the operational temperature beyond 700 °C. However, one of the main drawbacks of this medium consists in the severe corrosion problems to which its composition and high temperature lead. Thus, the development of protective coatings for steels could be an interesting alternative, both from a technological and economical point of view, for increasing the lifetime of pipes and tanks in contact with molten carbonates. In both cases, the levelized cost of electricity (LCoE) would suffer a substantial reduction, which is one of the major objectives currently set in CSP technology. Thus, this work aimed at developing zirconia-based sol-gel protective coatings (on stainless steels and monitoring the protective behaviour in contact with a eutectic ternary Li_2CO_3-Na_2CO_3-K_2CO_3. Corrosion tests were performed at 700°C up to 1000 h results were supported by gravimetric and microstructural characterizations. All results were compared to the uncoated steels. Results showed the promising behaviour of the coated substrates. The corrosion monitoring system showed the protective behaviour of the coatings, these improving the behaviour of the uncoated samples, where detachments and high weight variations were observed.

9:20am **A1-3-TuM-5 Experimental Study on Steam Oxidation Resistance at 600ºC of Inconel 625 Coatings Deposited by HVOF and Laser Cladding***,* ***Francisco Javier Pérez Trujillo (fjperez@ucm.es)****, G. García Martín, A. Illana Sánchez, T. De Miguel Gamo,* Universidad Complutense de Madrid, Spain*; F. Gonçalves , M. Sousa,* Tecnologia e Engenharia de Materiais , Portugal

Technological developments around electric generation power plants aim to increase the thermal efficiency of conversion processes in steam turbines, developing materials able to resist ultra-supercritical (USC) conditions (600-620°C and 20-30 MPa). 9-12 %Cr ferritic-martensitic steels, commonly used for that application, tend to develop thick and non-protective iron-rich oxide scales. Therefore, partial or complete spallation of these oxide scales may cause serious consequences for the lifetime and safe operation of the components in contact with the steam and even the own plant. The solution to prolong their service life is to modify their surface, by means of protective coatings that retard interdiffusion mechanisms that take place at that temperature range.

Inconel 625 is used for its high strength, excellent fabricability (including joining), and oxidation resistance up to 982°C, so has been considered as one possible candidate for A-USC power plants (up to 700°C and 35 MPa).

In this research Inconel 625 coatings were deposited by High Velocity Oxy-fuel (HVOF) and laser cladding (LC) processes on a 12%Cr steel to improve its oxidation resistance. A high-temperature oxidation test under isothermal conditions up to 500 h was performed on uncoated and coated steel in a pure steam atmosphere at 600°C. The specimens were weighed monitoring at different times during the testsand characterized before and after oxidation tests by X-ray diffraction (XRD) and scanning electron microscopy with energy dispersive spectroscopy (SEM/EDS). The results have shown that the application of Inconel 625 coatings reduces the weight gain of the steel by more than 50%. In addition, after 500 h of oxidation both coatings deposited by HVOF and LC exhibited an excellent oxidation resistance at 600°C in pure steam due to the formation of thin layers of protective Cr_2O_3 and $NiCr_2O_4$ oxides on the external surface of the coatings.

9:40am **A1-3-TuM-6 Oxidation Kinetics of γ-TiAl Based Coating Materials***,* ***Paul Mayrhofer (paul.mayrhofer@tuwien.ac.at)****, S. Kagerer, O. Hudak,* TU Wien, Austria*; M. Schloffer,* MTU Aero Engines, Muenchen, Germany*; H. Riedl,* TU Wien, Austria

The reduction of carbon emissions as well as the improving of fuel efficiencies tied to modern aerospace and aviation have heavily invested in the development of lighter and more durable high temperatures materials. γ-TiAl bulk materials, with their low density and distinguished creep resistance, fulfill all these tasks till 780°C. Above 780°C, oxidation protection of γ-TiAl based alloys is a challenging task for the aero- and automotive industry. Here, especially thin films rise the possibility to protect these alloys while not affecting other material properties. Typically, ceramic like thin films are applied to defend the bulk materials against oxidation and corrosion attacks. Within this study, we applied a different approach utilizing metallic coating materials deposited by PVD.

Therefore, we grow Al-rich γ-TiAl based coatings onto well-established TNM bulk alloys using a semi-industrial scaled unbalanced magnetron sputtering system. To study the oxide scale formation and its kinetics, also on a long-term view, all coatings were oxidized at 850 °C up to 1000 h in ambient air. The scale formation and accompanying diffusion processes have been investigated methodically by various electron imaging techniques (SEM and HR-TEM) as well as structural and chemical analysis. The prevalent diffusion process was separated in two dominating effects: *(i)* oxygen inward diffusion and outermost scale formation as well as *(ii)* Al interdiffusion between the coating and bulk interface. The so obtained diffusion lengths were used to estimate diffusion coefficients by the parabolic growth rate of the TGO and the oxygen inward diffusion by a logarithmic rate law. In a further step, morphological changes due phase transformation based on Al diffusion processes was investigated in detail. The highly dense, thermally grown oxide (alumina based scale) reaches a thickness up to maximum of 4 µm depending on the coating thickness (> 10 µm) leading to superior protection of the bulk material. In summary, the application of γ-TiAl based coating materials to enhance the oxidation resistance of TNM bulk alloys is an interesting alternative to ceramic like coatings, also on a long-term perspective.

10:00am **A1-3-TuM-7 The Impact of Aluminide Slurry Coatings on the Oxidation and Fatigue Resistance of High-Strength Ni-Based Valve Alloys***,* ***Sebastien Dryepondt (dryepondtsn@ornl.gov)****, R. Pillai , B. Armstrong, M. Lance, G. Muralidharan,* ORNL, USA

Increasing temperature in light and heavy-duty internal combustion engines offers a straightforward solution for increasing engine efficiency and reducing CO_2 emission. Development of new Ni-based high temperature alloys is, however, burdensome due to the need for both high strength and high oxidation resistance. One solution is to apply corrosion-resistant coatings to high strength materials. A slurry aluminide coating was, therefore, deposited on commercial (alloy 31V) and ORNL-developed high strength gamma prime Ni-based superalloys. A significant improvement of the alloy cyclic oxidation resistance at 900°C and 950°C in air + 10%H_2O was observed for both alloys due to coating application. The coated ORNL sample exhibited more rapid oxidation rates than the 31V coated sample due to the higher Ti concentration in the former alloy leading to the formation of Ti-rich nonprotective oxides. High cycle fatigue testing was also conducted on bare and coated specimens to assess the coating impact on the alloy fatigue resistance at 800-900°C. Similar cycles to rupture were measured for the bare and coated samples, confirming that the coated ORNL alloy is a viable option for valve application up to ~900°C. Further optimization of the substrate/coating couple could allow for even higher valve operating temperature.

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