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Meet Our New Colleagues

This column presents selected currently graduating Ph.D. students in the thermal spray field from around the world. Students planning to graduate in the area of thermal spray within the next three to six months are encouraged to submit a short description (one to two pages, preferably as a Word document) of the projects they performed during their studies to Jan Ilavsky, JTST associate editor, address: Argonne National Laboratory, Advanced Photon Source, 9700 S. Cass Ave., Argonne, IL, 60439; e-mail: JTST.Ilavsky@aps.anl.gov. After limited review and corrections and with agreement of the student's thesis advisor, selected submissions will be published in the upcoming issues of JTST.

Hot Corrosion Studies on Plasma Spray Coatings over Some Nickel- and Iron-Base Superalloys

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Abstract of Research

Plasma sprayed deposits on selected nickel- and iron-base superalloys were characterized in the as-sprayed condition. Subsequently oxidation behavior of the uncoated as well as coated superalloys was investigated in air and in molten salt environment (Na_2SO_4-60%V_2O_5) under cyclic conditions. The studies were performed in a silicon tube furnace for 50 cycles; each cycle consisted of 1 h heating at 900 °C followed by 20 min cooling.

The coatings were deposited using 40 kW Miller Thermal (USA) plasma spray system. Four compositions of coatings were used: Ni-22Cr-10Al-1Y (NiCrAlY), Ni-20Cr, Ni_3Al, and Stellite-6. Approximately 150 μm thick layer of NiCrAlY was applied as a bond coat before deposition of the top layer of approximately 200 μm in all cases. All the coating powders were commercially available except the Ni_3Al powder, which was prepared by mixing nickel and aluminum powders in the stoichiometric ratios in a ball mill. In as-sprayed condition, the formation of Ni_3Al as main phase was confirmed by XRD analysis. The plasma sprayed coatings were found to have some porosity.

Results

Conclusions from this study are:

- During oxidation studies in air, all of the coatings have shown overall weight gains higher than their uncoated counterpart superalloys. In most of the coated cases, the oxidation behavior was found to be governed by parabolic rate law, which indicates that the coatings were able to act as diffusion barriers to the oxidizing environments. Further, the conclusions regarding the usefulness of the coatings were derived from the formation of protective oxides and spinels in the oxide scales and from the fact that the base superalloys did not suffer internal oxidation.
- In the case of studies in air, the NiCrAlY coated superalloys showed minimum rate of oxidation among all of the coated superalloys. Ni_3Al appeared to be the second best compared with Ni-20Cr and Stellite-6 coatings in most of the cases. This resistance might also be imparted by the presence of a thin continuous streak of chromium at the interface between the bond coat and the base alloys. On the contrary, the relatively low oxidation resistance shown by Ni-20Cr coatings might be attributed to absence of such continuous chromia layers. Furthermore, the high weight gain in this case might also be contributed by the comparatively high magnitude of minor spallation of this coating from/near the edges.
- In the molten salt environment, the coatings were found to be successful in reducing the overall weight gain in most of the cases, hence reducing the corrosion rates. The coatings could be ordered as follows on the basis of the role in developing hot corrosion resistance:

  NiCrAlY > Ni-20Cr > Ni_3Al > Stellite-6

- The best protection by NiCrAlY coating in both the environments of study might be attributed to the simultaneous formation of an additional protective oxide α-Al_2O_3 along with Cr_2O_3 and $NiCr_2O_4$. According to Toma et al. (1999), α-Al_2O_3 grows very slowly and is thermodynamically stable. Moreover, the presence of yttrium in the coating might have played its role in reducing the scale growth rate and hence the overall weight gain reduction (Tawancy et al., 1994).
- In the current study, comparatively loose structure scales were seen for Ni_3Al coated superalloys, which might be responsible for slightly lower corrosion resistance shown by this coating. Also, the presence of some aluminum-depleted zones in the top scales in most of the cases might also be affecting its corrosion resistance.
- Relatively lower oxidation resistance of the Stellite-6 coated superalloys in the molten salt environment might also be ascribed to low chromium content in the coating composition, and the comparatively high extent of superficial cracking and spalling of the coatings near or along the edges of the specimens.
- The effect of the base superalloys was considerable in most of the cases on the oxidation behavior in air and molten salt, except in case of air oxidation of the Ni_3Al coated nickel-base superalloys, and NiCrAlY coated superalloys, where the oxidation rates were not significantly apart.
- The most common feature in case of oxidized coatings in both air as well as molten salt atmosphere was the presence of protective oxides and spinels in the top scales and of chromium-rich layer present in the scale just above the scale/substrate interface or tendency toward formation of such layer. Further, blocking of porosity and splat boundaries by formation of oxides in the transient period of oxidation was also a general attribute of the proposed oxidation and hot corrosion mechanisms. In most of the cases, the parabolic rate law of oxidation was followed, although minor deviations were observed in all the cases.
- In most of the cases of coated superalloy samples subjected to molten salt

environment, sulfur penetrated into the base superalloys and formed sulfides, while vanadium diffused mainly in the top scales.

- The electron probe microanalysis indicated diffusion of some of the basic elements of the superalloy substrates such as iron, titanium, manganese, molybdenum, tantalum, and silicon into the scales in many cases.
- Only minor spalling of the scales was observed in powder form in all the coated cases, when subjected to molten salt corrosion, which was not very significant. The scales in general showed no tendency toward spalling/cracking and were found intact.
- Some superficial minor cracks were observed near/along the sharp edges of the coated specimens in nearly all the coated superalloy specimens during cyclic oxidation in air as well as molten salt environments. This could be attributed to the difference in thermal expansion coefficients of top coat, bond coat, and substrate. This cracking further resulted in disintegration/spalling of the edges of the coatings, which was marginal.

Publications

Research papers presented /published out of this investigation:

- S. Prakash, D. Puri, and H. Singh, Hot Corrosion Behavior of Plasma Sprayed Coatings on a Ni-Based Superalloy in Na_2SO_4-60%V_2O_5 environment, *ISIJ Int.,* submitted for publication
- H. Singh, D. Puri, and S. Prakash, Some Studies on Hot Corrosion Performance of Plasma Sprayed Coatings on a Fe-Based Superalloy, *Surf. Coat. Technol.,* Vol 192, 2005, p 27-38
- H. Singh, D. Puri, and S. Prakash, Corrosion Behavior of Plasma Sprayed Coatings on a Ni-Base Superalloy in Na_2SO_4-60%V_2O_5 Environment at 900 °C, *Metall. Mater. Trans. A,* in press
- H. Singh, D. Puri, and S. Prakash, Studies on Plasma Spray Coatings on a Fe-Base Superalloy with Regard to its Structure and High Temperature Oxidation Behavior, *Anti-Corros. Method. Mater.,* accepted for publication
- H. Singh, D. Puri, and S. Prakash, High Temperature Oxidation Behavior of Plasma Sprayed NiCrAlY Coatings on Ni-Based Superalloys in Air, presented and published in International Symposium of Research Scholars on *Materials Science and Engineering* held on Dec 20-22, 2004 at IITM, Chennai, and to be published in *Trans. Indian Inst. Met.*
- H. Singh, D. Puri, and S. Prakash, An Overview of High Temperature Oxidation of Metals and Alloys, presented and published in Indo-Japan Conference on *Damage Tolerant Design and Materials,* held on Dec 16-18, 2004 at IITM, Chennai
- H. Singh, D. Puri, and S. Prakash, Hot Corrosion of Some Superalloys and Role of Plasma Spray Coatings—A Review, presented at Seventh Punjab Science Congress held at GNDU, Amritsar on Feb 7-9, 2004