COMPATIBILITY OF GAS TURBINE MATERIALS WITH STEAM COOLING

June 1, 1994 to August 18, 1995

Final Report

Principal Investigator: Dr.Vimal H. Desai
Graduate Research Assistants: Dnyanesh Tamboli, Yakin Patel

Materials Science & Engineering Program
Mechanical & Aerospace Engineering Department
University of Central Florida,
Orlando, FL 32816

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EXECUTIVE SUMMARY

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Materials Science & Engineering Program
Department of Mechanical & Aerospace Engineering
University of Central Florida
Orlando, FL 32816
Ph: (407) 823-5777 Fax: (407) 823-0208

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Rationale:

Steam as an alternate cooling agent offers attractive advantages because of its higher specific heat (almost twice that of air) and lower kinematic viscosity. However, steam cooling may lead to several materials related problems that warrant attention prior to its introduction in ATS. The effects of steam and its impurities on superalloys are little known. For the continuous reliable operation of gas turbines this information is very vital, so that alternatives can be considered and allowances can be made. Therefore, the objective of the first year of this research program was to investigate the nature and the extent of materials degradation problems that may be encountered when steam is used as a cooling medium for cooling the hot gas path components. In the planning of the experiments in the first year a major emphasis was put on studying effects of prolonged exposure of the superalloys to steam as it was believed that the short term kinetics data may not be sufficient to give information about the extent and the nature of attack the gas turbine superalloys would encounter during steam cooling. The results obtained appeared to validate the approach taken.

Experimental Set-Up

The first three months of this project were spent on design and fabrication of a multiple steam generator facility. This in-house built 5 KW steam generator facility offered several advantages. Among them are the simultaneous generation of a number of environments and easier control over pressure and the flow rate of the steam. This steam generator performed flawlessly in a continuous manner.

The alloys chosen for the study are IN738, X-45 and IN617 which are commonly used for blade, vane and transition piece, respectively. The specimen geometry is cylindrical with a 1/4" diameter central bore through which steam is passed. The specimens were stationed in an oven maintained at

840^0 C. The incoming steam velocity was maintained at about 1 ft./sec. In order to study the effect of impurity contents, three different steam environments are used namely "aggressive", "mild" and "pure". These environments are created by adding NaCl and Na_2SO_4 salts in different concentration (5 ppm each for "mild" and 50 ppm each for "aggressive" steam) to the distilled and deionized water used for steam generation. The rationale behind using high salt concentration was that even though industrial feed water chemistry control would allow the concentrations of the salts within few ppm range, the high contaminant flux rates because of high steam flow rates and localized concentartion of the impurities may generate conditions as in our experiment. The specimens were exposed to "clean" steam for 3900 hours, "mild" steam for 2950 hours and " aggressive" steam for 1450 hours. The different methods used for the evaluation of material damage include various microscopic techniques and Electrochemical Impedance Spectroscopy (EIS).

Important Results

Steam Oxidation

The most important result of this study has been the extensive oxidation of IN 738 in steam compared to other alloys. IN 738 has higher aluminum compared to the other alloys used in this study. This higher level of Al is generally found to be beneficial for high temperature oxidation resistance of the superalloys. In case of IN 738 it was observed after prolonged exposure (3900 hours) in "clean" steam environment that the oxides formed were non-protective in nature and there was severe internal oxidation of the alloy with Al rich oxide stringers extending up-to 77 microns (30 mils) inside the substrate. IN 617 showed compact and layered protective oxide scale structure. Internal Al rich oxide stringers were also observed, but the extent of internal oxidation is limited due to lower Al content. X-45 which has a very large Cr content and no compositional Al shows the lowest damage. An explanation is put forward to explain this behavior based on the low oxygen partial pressures in the steam which would tend to preferentially oxidize aluminum from the alloy and also possible hydration of the oxides leading to non-protective scale formation.

Hot Corrosion in Steam

In salt containing environments the damage in IN 617 was the highest. The high internal penetration and the oxide scale damage in IN 617 may be attributed to the acidic fluxing due to higher Mo content and due to the effect of NaCl. The sulfidation damage in IN 738 and X-45 was observed to be relatively small. The mode of degradation in IN 738 even in salt containing steam was by oxidation rather than sulfidation. The resistance of X-45 to sulfidation may be attributed to higher chromium level (about 25.5 % in this alloy).

Electrochemical Impedance Spectroscopy (EIS)

This novel non-destructive test mainly used to study aqueous corrosion phenomenon was used in this study to examine the properties of the oxide scales such as oxide scale integrity and porosity. This data obtained technique gave a good qualitative corroboration with microscopic observations. This technique is currently being refined for the use as a non-destructive life prediction tool.

Future Direction

This project was initially started as an one year project to see if steam has any detrimental effects on materials properties. Since no information is currently available in literature about steam-gas turbine superalloy interaction, the purpose of this study was to mainly examine long term effects of steam and the impurities on the superalloys and to see whether there is a cause for concern. In this project the problems associated with steam-superalloy interaction were identified. This project has been granted two year extension. In that period, a number of variables such as temperature, pressure and stress will be introduced to examine how these parameters affect the mode of attack. New alloys such as CMSX-4 single crystal alloy will also be included in this study. The effectiveness of the aluminide coatings and inhibitors for protection in steam will also be evaluated. A detailed study would be performed to investigate the mechanism of the oxidation and the kinetics.

Industrial Interaction

From the beginning a close interaction and collaboration was setup with the Materials Division, Westinghouse Power Generation Business Unit, Orlando, FL. Dr. Sastry Cheruvu is the primary contact on this research project. In the design of the experiment set-up as well as interpretation of the results, continual feed back was obtained. Regular joint meetings were with Dr. Sastry of Westinghouse and the students working on this project. New test configurations, materials and frequency of testing was continually updated.

A close interaction is also being established with Dr. Ian Wright of Oak Ridge National Research Laboratory, Oakridge, TN. Discussions held with him also gave lot of inputs for this project.

As a result of continual interaction with the industry a number of new ideas were generated. The most important new research activity generated out of this interaction was a project on the suitability of single crystal aero-derivative CMSX-4 superalloy for the land based gas turbine application. A technical collaboration is being established for this project between Westinghouse (Dr. N.S. Cheruvu), Solar Turbine (Dr. Ken Kubarych).

One of the students working on this AGTSR funded project won the AGTSR Industrial Internship at Westinghouse PGBU, Orlando, FL durring summer of 1995. he was eventually hired as an Associate Engineer by Westinghouse.