Project Title: Interaction of Steam/Air Mixtures With Turbine Airfoil Alloys and Coatings

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## ABSTRACT

Hot section distress in gas turbines is typically more severe when steam injection is used. The data that exist in the literature show that steam, or water in the gaseous state, can have a variety of effects on the oxidation of alloys. These effects depend upon the alloy under consideration, the oxidation temperature, the water vapor pressure, and the gas flow rate. Two of the most serious effects of water vapor or steam on the high temperature oxidation of alloys is in the increased spalling tendencies of $Al_2O_3$ and $Cr_2O_3$ scales, and the increased volatilization of certain oxides. In this program $Al_2O_3$ and $Cr_2O_3$ scales are being emphasized because these two oxides are the basis for development of oxidation resistance in modern superalloys

This program is directed at determining how high temperature and pressure steam affect the oxidation of materials proposed for use in current and advanced gas turbines. The approach is to first quantify how steam affects the oxidation of selected alloys and coatings by investigating the dependence of oxidation rates on temperature, steam pressure in air, and the gas mixture flow rates, and to then attempt to understand the changes in oxidation mechanisms and mechanical properties that lead to the observed oxidation rate changes. Three pieces of equipment are being used to investigate the oxidation of selected alloys over the required ranges of conditions. The range of experimental conditions that can be established by this equipment is as follows. Apparatus 1 permits testing at steam pressures up to one atmosphere at temperatures up to 1100°C with gas velocities between 0.07 and 10 cm/s. Apparatus 2, located at Oak Ridge National Laboratory, permits testing at steam pressures greater than one atmosphere at temperatures between 700 and 1100°C at a gas velocity of 0.07 cm/s. Apparatus 3 permits testing at high gas velocities at temperatures between 700 and 900°C with steam pressures between 0.1 and 0.3 atm.

Cyclic oxidation tests have been performed at 900°C for 1600 hours in dry air and air with 0.3 atm. of water vapor on Mar M 247, X-40, IN 738, CM 186, N5 and PWA 1484. These alloys have also been exposed isothermally at 900°C in steam at a pressure of 250 psi. The major effect of steam at 900°C has been to cause more sever cracking and spalling of oxide scales. This cracking and spalling occurs at water vapor pressures of 0.3 atm. under cyclic conditions but higher steam pressure (250 psi) under isothermal conditions did not cause more severe degradation. The alloys that developed $Cr_2O_3$ during oxidation (i.e. X-40, IN 738) were degraded more than alloys that developed $\alpha$-$Al_2O_3$ scales (i. e. N5, PWA 1484, CM 186).

Water vapor also caused increased degradation at 700°C but the major cause of this degradation was less effective selective oxidation from the alloys. The alumina-formers were more substantially affected by this phenomenon than the chromia formers. These effects occurred during cyclic oxidation with a water vapor pressure of 0.3 atm. As observed at 900°C, the presence of steam at 250 psi during isothermal oxidation did not cause as much degradation as water vapor at lower pressures but under cyclic conditions.

Experiments have also been performed to examine the effects of gas velocity during oxidation in dry and wet air. Gas velocity has not been found to substantially affect the oxidation behavior of the alloys that have been studied.