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

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Introduction

This program was initiated on February 1, 1999. It is directed at determining the effects of high pressure and temperature steam on the oxidation of turbine airfoil alloys and coatings. The experimental approach being utilized consists of exposing alloys and coatings to a variety of different conditions (temperature, steam pressure, gas flow rates) and to compare the degradation rates of the different alloys and coatings. Another important objective of this program is to describe the effects of temperature, steam pressure and gas flow rates on the degradation processes of the different alloys. A final objective of this program is to examine the effects of applied stress on the oxidation of alloys in dry air and in steam.

The alloys and coatings being investigated in this program include IN 738, X-40, CM 186, MarM 247, CMSX 4, N5, PWA 1484, and aluminide coated CMSX 4 and N5.

An important aspect of this investigation is the means by which the degradation rates of the alloys are determined and compared. The planned procedure is to use weight change versus time measurements complimented by detailed metallographic analysis (optical metallography, scanning electron microscopy, x-ray diffraction) of exposed specimens.

In the following the experimental approaches to be used to obtain the desired steam pressures and gas velocities are described, and the techniques to evaluate the results are discussed. The results obtained from the initial tests are then presented and used to describe the oxidation behavior of some of the alloys.

Oxidation Test Methods Being Used in This Program

In this program it is necessary to examine test temperatures between 700°C and 1100°C, steam pressures from as low as 0.1 atm to as high as 15 atm, and gas flow rates from about 0.1 cm/s to 100 m/s. In order to define and control the test variables over such ranges three different apparatuses are being used. In the following each of these apparatuses is described, and the techniques to evaluate the test results are discussed.

Apparatus No 1

Apparatus no 1 is located at the University of Pittsburgh and it is shown schematically in Figure 1. In this apparatus testing in air-steam gas mixtures at a total pressure of 1 atm with steam partial pressures from virtually zero to 0.7 atm can be performed at temperatures between 700°C to 1100°C using gas flow rates extending from 0.07 cm/s to 10 cm/s. With the results that are obtained from tests in this apparatus the following observations will be made in regard to the effects of steam pressures, gas flow rate, and the oxidation temperature:

- The effects of steam pressures on the degradation rates of the various alloys will be obtained at a constant temperature and a constant gas flow rate (~ 1 cm/s) where the steam partial pressure range extends from about 0.1 to 0.7 atm at a total gas pressure of 1 atm.

- The effects of gas flow rates on the degradation of the various alloys and coatings will be obtained at a constant temperature and a constant steam partial pressure (~ 0.3 atm) where the gas flow rates extend from 0.07 cm/s to 10 cm/s.

- The effects of temperature on the oxidation degradation of the various alloys and coatings will be obtained at a constant steam partial pressure (~ 0.3 atm) and a constant gas flow rate (~ 1 cm/s) where the temperature range extends from 700°C to 1100°C.

Apparatus No 2

Apparatus no 2 is located at the University of Pittsburgh and is shown in Figure 2. In this apparatus tests can be performed at gas velocities up to 150 m/s. This apparatus is to be used to examine the oxidation of the various alloys at a steam pressure of 0.1 atm and in dry air using gas flow rates of 50, 100 and 150 m/s. The test temperatures will be 700°C and 800°C. The results obtained will be used to:

- compare the effects of steam on the oxidation of the various alloys at high gas velocities approaching 0.5 mach.

- compare effects of low gas velocities (~1 cm/s) to high gas velocities (~150 m/s) on the oxidation of alloys in steam.

Apparatus No 3

Apparatus no 3 is located at Oak Ridge National Laboratory and permits testing of specimens at different temperatures at steam pressures up to 15 atm at a gas flow rate of 0.07 cm/s. Testing of specimens will be performed in this apparatus to examine steam effects at pressures greater than 1 atm. The results obtained in this apparatus will be used to:

- compare the effects of high steam pressures (~5-15 atm) on the oxidation degradation of the alloys.

- compare the effects of steam pressures on oxidation of alloys over two ranges of steam pressures, mainly 0.1-0.7 atm and 5-15 atm.

Experiments to Investigate the Effects of Applied Stress on the Oxidation of Alloys in Steam-Air Mixtures

In order to investigate the effects of applied stress on the oxidation of selected alloys in dry air and in the presence of steam, two-point and three-point fixtures are being designed for insertion into the hot section of Apparatus 1, Figure 3. These fixtures are being made of a nickel alloy with the same coefficient of thermal expansion as the specimens (which can be important for the two-point bend test). Fixture and specimen geometries are based on standard tests used for stress corrosion studies (ASTM standard G39-90).

As shown in Figure 4, the stress-oxidation specimens are thin rectangular cross-sectioned strips. Both fixtures subject a single specimen to a range of tensile and compressive stresses occurring at the location mid-way along the specimen length. The two-point bend configuration achieves this by an elastic buckling of the strip, which eliminates the region of stress concentration seen at the midpoint of a specimen loaded under three-point bending. Analysis of the buckled strip can be complicated, however, so the simpler three-point bend geometry will also be used. These tests are planned to be performed on two alloys, an alumina-former (MarM 247) and a Cr_2O_3-former (IN 738). The effects of stress will be evaluated by comparing the oxidation degradation of specimens oxidized with and without applied stresses.

Results Obtained From Initial Tests in Apparatus No. 1

- Specimens of MarM 247, IN 738 and X-40 have been tested at 900°C cyclically (45 minutes hot, 15 minutes cold zone) in an air-steam mixture with P_{H2O} = 0.3 atm at a total pressure of 1 atm with a gas flow rate of 0.07 cm/s. Some of the test results are presented in Figure 5 where it can be seen that IN 738 exhibits much larger weight changes than either X-40 or MarM 247. These results also show that both IN 738 and X-40 eventually begin to lose weight whereas MarM 247 continually increases in weight at a very slow rate. These results show that IN 738 and X-40 are not as resistant to oxidation under these conditions as is MarM 247. This conclusion has been confirmed by metallographic examination of the exposed specimens which is currently in progress. The degradation of IN 738 was substantially greater than that evident in MarM 247. The degradation of X-40 was not markedly more severe than MarM 247, but specimens must be compared after times in excess of 2500 cycles for which substantial differences in weight change were evident. These specimens are still being tested and will be examined metallographically in the near future.

- The results that are presented in Figure 5 indicate that the time at which weight changes per unit area approach zero may be used as a measure of the oxidation degradation. For example, the weight changes for both IN 738 and X-40 approach zero at about 2200 cycles whereas such a time for MarM 247 is going to be much larger than this number of cycles. More work is required to justify using this time as a measure of degradation.

- The different oxidation behavior for MarM 247, and X-40 and IN 738 are believed to be due to the oxides that form during oxidation. MarM 247 is an alumina former whereas X-40 and IN 738 are Cr_2O_3-formers. More work is necessary, but it is proposed that Cr_2O_3 develops more volatile oxides in the presence of steam.

Summary and Future Work

The initial results that have been obtained indicate that steam may cause more severe oxidation degradation of alloys that rely on the development of Cr_2O_3 scales for protection than alloys which form alumina scales. Oxidation testing in Apparatus 1 will be continued to compare alloys at different temperatures and at different (low) steam pressures. The data obtained in Apparatus 1 is now being used to select alloys and conditions for testing in Apparatus 2 (high gas velocities) and Apparatus 3 (high steam pressures).

Acknowledgements

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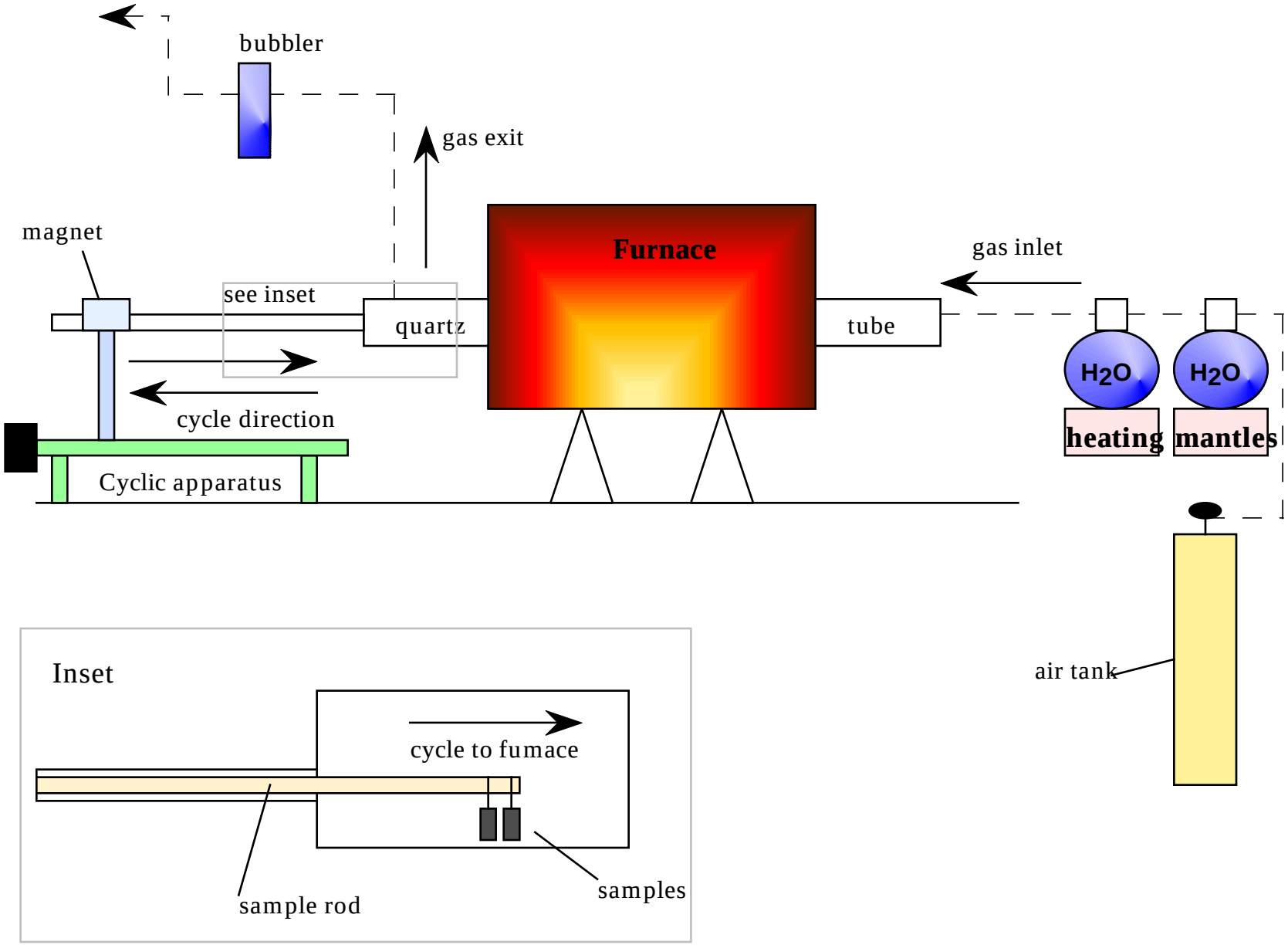
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Figure 1

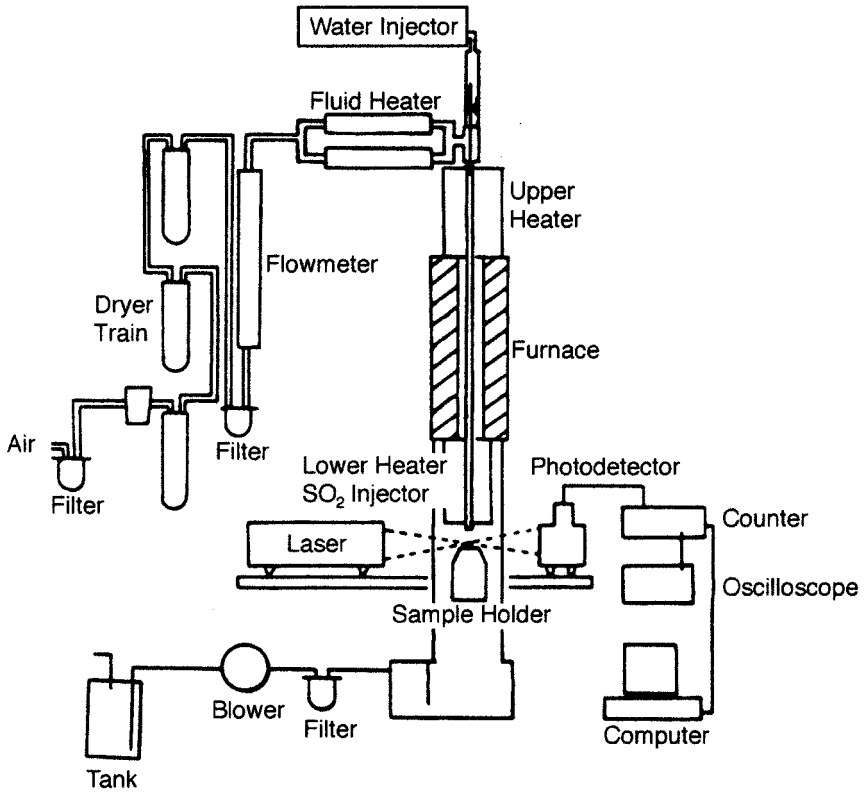
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Figure 2

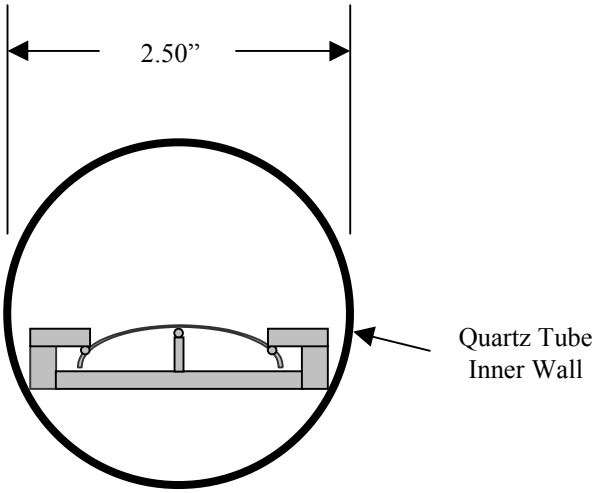

Figure 3.
Diagram of a Point Fixture Mounted Transversely in a Quartz Tube in Apparatus No. 1

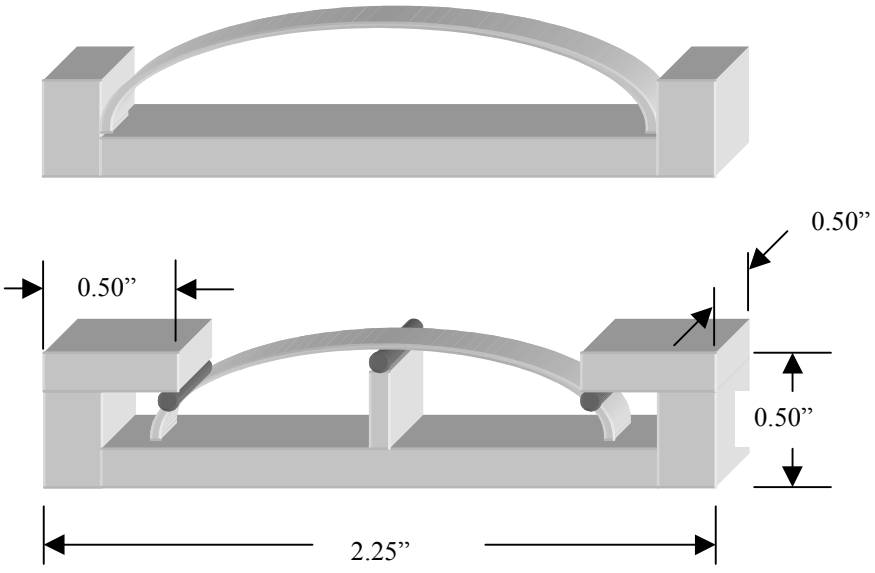

Figure 4. Two-Point and Three-Point Bend Stress Oxidation Tests

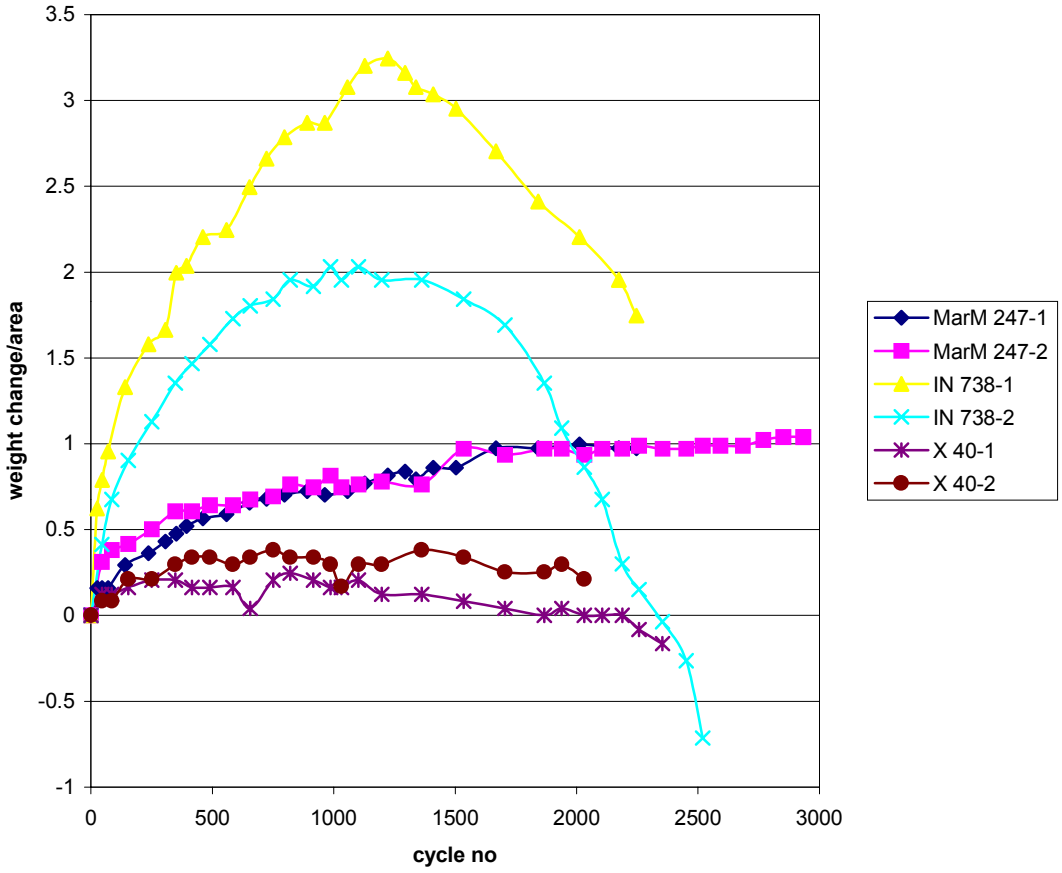

Figure 5.
Weight change versus time measurements for the cyclic oxidation of IN 738, MarM 247 and X-40 at 900°C in a steam-air gas mixture at a total pressure of 1 atm and a partial pressure of steam equal to 0.3 atm.