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COATING LIFE PREDICTION

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Hot-section gas-turbine components typically require some form of coating for oxidation and hot-corrosion protection. These coatings are generally either aluminide coatings or MCrAlY overlay coatings, where M represents nickel, cobalt, or a combination of these two elements. Both coating types are protective as a result of the selective oxidation of aluminum to form an external, continuous Al_2O_3 scale. The coatings act as a reservoir of aluminum since the aluminum content of the coating is always greater than that of the substrate. Any mechanism which reduces the aluminum content of the coating degrades the coating. Two significant forms of degradation which occur in aero gas-turbine engines are oxidation and coating-substrate interdiffusion. Coating-substrate interdiffusion involves not only the loss of the aluminum from the coating into the substrate but also the diffusion of less desirable elements to the coating surface where they may oxidize and hinder or prohibit the formation of the Al_2O_3 scale. In addition, cycling of a coated component results in cracking and spalling of the Al_2O_3 scale, which further accelerates coating degradation.

Efficient use of coatings requires reliable and accurate predictions of the protective life of the coating. Currently, engine inspections and component replacements are often made on a conservative basis. Consequently, there is a continuing need to improve and develop the life-prediction capability of metallic coatings in various service environments. The purpose of the present work is to develop an improved methodology for predicting metallic coating lives in an oxidizing environment and in a corrosive environment.

APPROACH

The present investigation combines both experimental studies and numerical modeling to predict coating life in an oxidizing environment. The experimental work provides both input to and verification of two numerical models. The coatings being examined are an aluminide coating on Udimet 700 (U-700), a low-pressure plasma spray (LPPS) Ni-18Co-17Cr-24Al-0.2Y overlay coating also on U-700, and bulk deposits of the LPPS NiCoCrAlY coating. The approach taken in this study is shown schematically in figure 1.

Experimental Testing

The experimental testing involves isothermal and cyclic furnace oxidation at 1050, 1100, and 1150 °C. In addition, Mach 0.3 cyclic burner rig testing of the aluminide and LPPS NiCoCrAlY coating (125 and 625 μm thicknesses) on U-700 is also being undertaken at 1100 and 1150 °C. Isothermal oxidation of the coated U-700 and bulk coating yields the growth rate of the Al_2O_3 scales which form on these coatings. Cyclic furnace and burner-rig oxidation yield the weight changes of the coated specimens reflecting the oxide growth and spallation which occurs during thermal

cycling. Analysis of the coating after an oxidation exposure includes x-ray diffraction and polarized light metallography of the retained surface oxides, observation of microstructural changes, scanning-electron microscopy, and electron microprobe analysis to measure concentration profiles across the coating and substrate. Only the experimental results for the furnace testing of the LPPS coating on U-700 will be discussed in the remainder of this paper.

Numerical Modeling

Two computer models are being used to predict the oxidation-limited life of the metallic coatings. A spalling model predicts the oxide growth and amount of oxide spallation which occurs during cyclic oxidation. The isothermal oxide growth rate and spall fraction Q_o (the ratio of the oxide which spalls on cooling to the total oxide present before cooling) are input to the spalling model. The spalling model predicts both the weight change of a coated specimen undergoing cyclic oxidation and the rate and total weight of metal consumption during cyclic oxidation. A diffusion model simulates the diffusional transport associated with both oxidation of the coating and coating-substrate interdiffusion. Diffusion coefficients and the rate of metal consumption predicted by the spalling model are inputs to the diffusion model. The diffusion model predicts aluminum and chromium concentration profiles in the coating and substrate and the time for which the coating is able to supply sufficient aluminum to continue forming an Al_2O_3 scale. The diffusion model, therefore, predicts coating failure when there is insufficient transport of aluminum to the oxide scale.

CURRENT STATUS AND RESULTS

Experimental

Isothermal furnace oxidation testing for 100 hr at 1050, 1100, and 1150 °C is complete. Cyclic furnace testing of the coated U-700 was carried out to failure of the coating at the three test temperatures (1050, 1100, and 1150 °C). Each of the coatings on the U-700 failed prematurely due to massive spallation of the coating (fig. 2). This premature coating failure was due to excessive porosity formation at the coating-substrate interface. The coating, significantly detached from the substrate, spalled first from the cylinder ends, permitting extensive oxidation at the coating-substrate interface via the interconnected porosity.

Numerical Modeling

The spalling model was used to predict the rate of aluminum consumption at 1050, 1100, and 1150 °C. The spall fraction Q_o, input to the spalling model, was chosen so as to reproduce the specimen weight change during cyclic oxidation before the onset of massive coating spallation (fig. 4). The weight of aluminum consumed, as predicted by the spalling model, for each test temperature is shown in figure 5. (Parameters input to the spalling and diffusion models, except as indicated otherwise in a figure, are shown in table I.)

The diffusion model predicted the aluminum and chromium concentration profiles after cyclic oxidation at 1050, 1100, and 1150 °C. Good agreement was found between the measured and predicted profiles (figs. 6 and 7) Following this verification of its predictive ability, the diffusion model was then used to examine the effect of

various parameters (e.g., coating thickness, spall fraction Q_o, and substrate composition) on coating life. The model was also used to predict the life of the NiCoCrAlY coating on U-700 for the case where massive coating spallation had not caused premature failure (fig. 8).

FUTURE WORK

Current burner-rig testing should provide oxidized specimens which, although containing porosity at the coating-substrate interface, eliminate oxide formation within the porosity and the resultant premature coating failure. An accurate test of the life predictive ability of the diffusion model could then be conducted. A second diffusion model is being developed to simulate γ' and β depletion during degradation of aluminide coatings. This aluminide diffusion model should be capable of predicting coating life. Measured concentration profiles after cyclic oxidation of the aluminide coated U-700 will be compared with those predicted by the diffusion model to determine the accuracy and usefulness of the aluminide diffusion model. Predicted and measured coating lives will also be compared. The conclusion of this work should result in an improved methodology for predicting the oxidation life of both overlay and aluminide coatings.

DUAL CYCLE ATTACK

An experimental study to investigate the effect of aging in a corrosive environment (900 °C, 0.5 ppm Na) on the oxidation life of the two coatings discussed in this paper has begun. An attempt will be made to develop an empirical model to relate coating life to combined oxidation and hot-corrosion cyclic exposure.

INPUT PARAMETERS FOR MODELS

TEMPERATURE, °C	SPALLING MODEL		DIFFUSION MODEL		
	WEIGHT CHANGE, Δw	SPALLING FRACTION, O_o	COATING COMPOSITION	COATING THICKNESS, μm	SUBSTRATE COMPOSITION
1050	$0.263t^{0.234}$	0.0004	Ni-16.7Cr-24.0Al	120	Ni-15.6Cr-8.4Al
1100	$.212t^{0.323}$	0.00075 - 0.0015			
1150	$.268t^{0.337}$	0.011			

OXIDATION-LIMITED COATING LIFE PREDICTION

OBJECTIVE: TO DEVELOP AN IMPROVED METHODOLOGY FOR PREDICTING THE OXIDATION LIFE OF METALLIC COATINGS

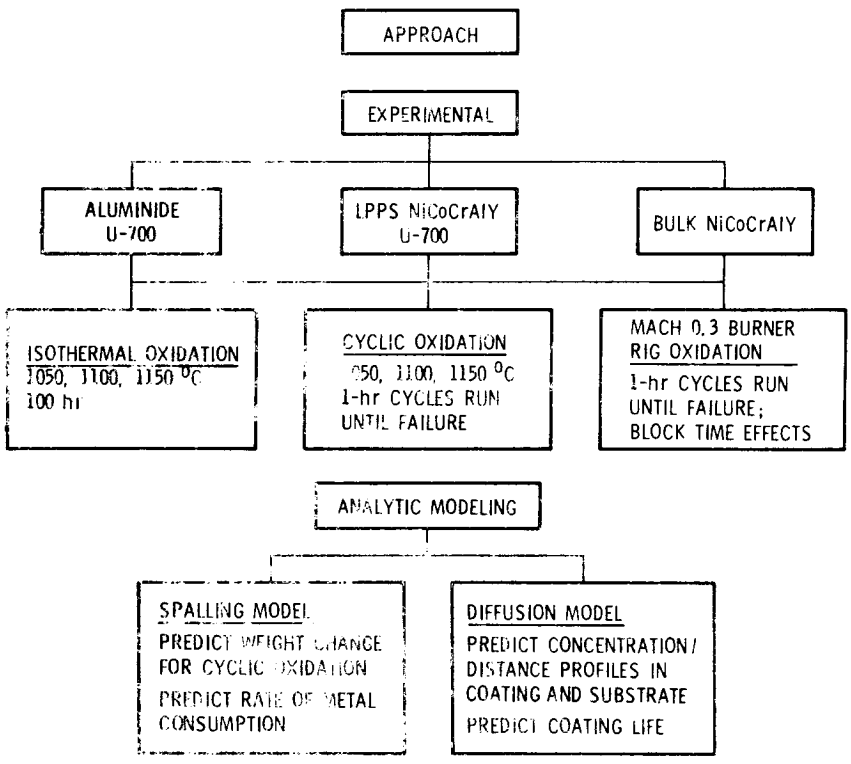

Figure 1

MACROSCOPIC COATING FAILURE

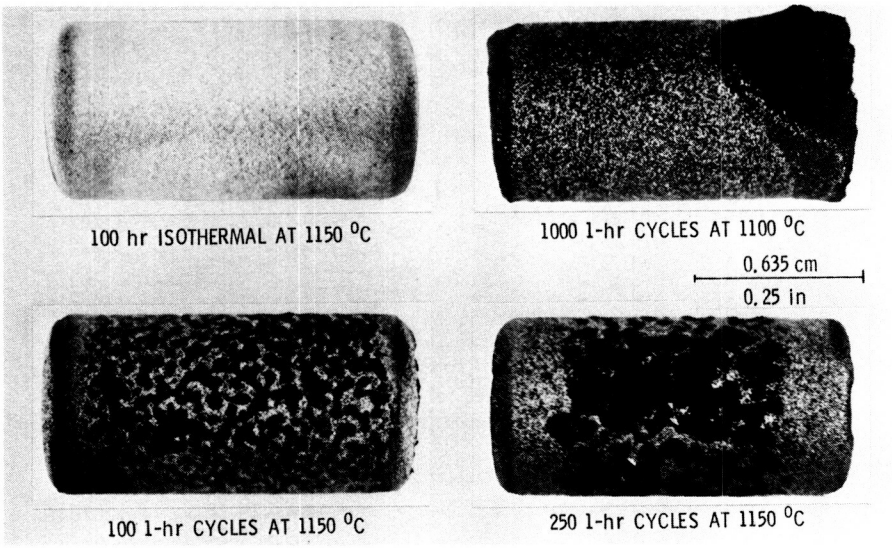

Figure 2

MICROSCOPIC COATING FAILURE
1150 °C

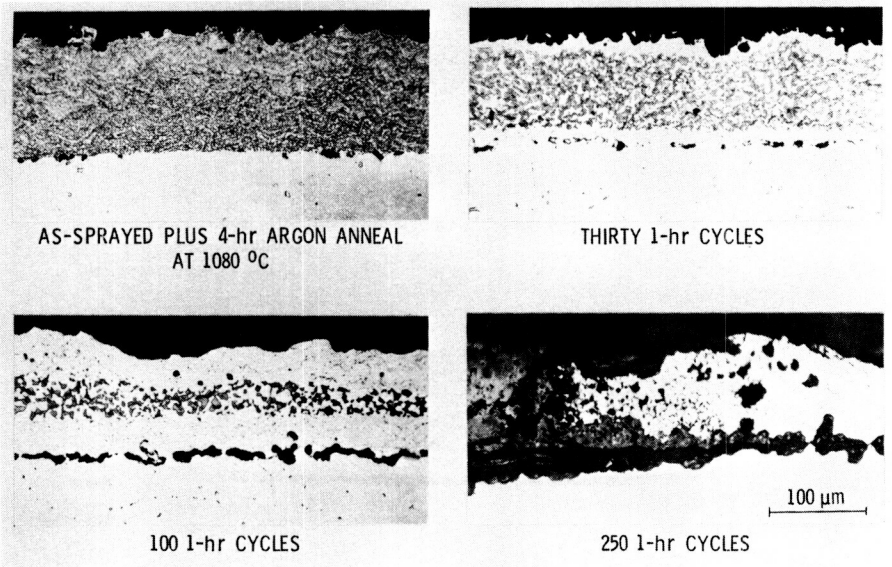

Figure 3

ALUMINUM CONSUMPTION PREDICTED BY SPALLING MODEL

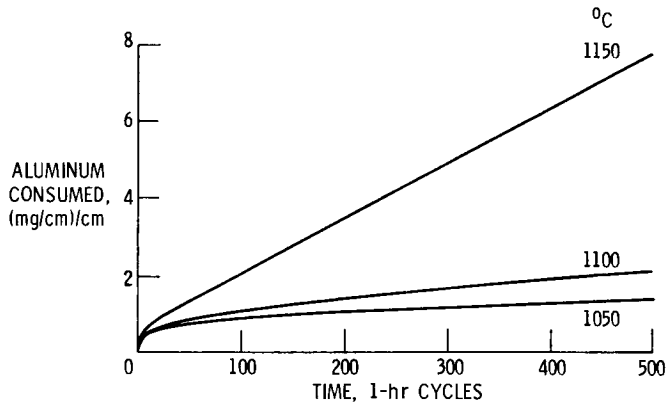

Figure 4

WEIGHT CHANGE DURING CYCLIC OXIDATION

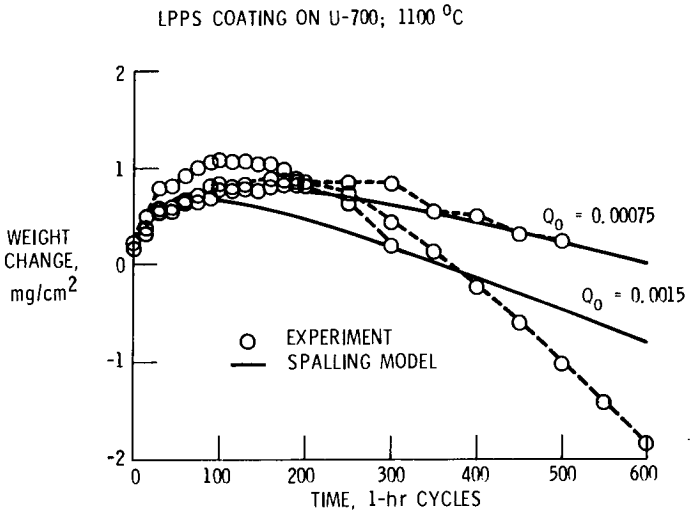

Figure 5

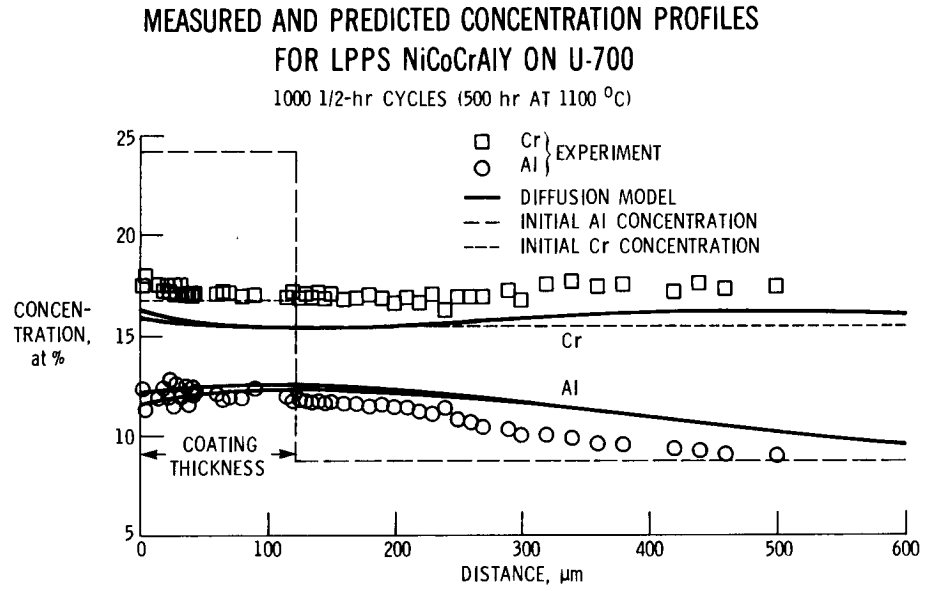

Figure 6

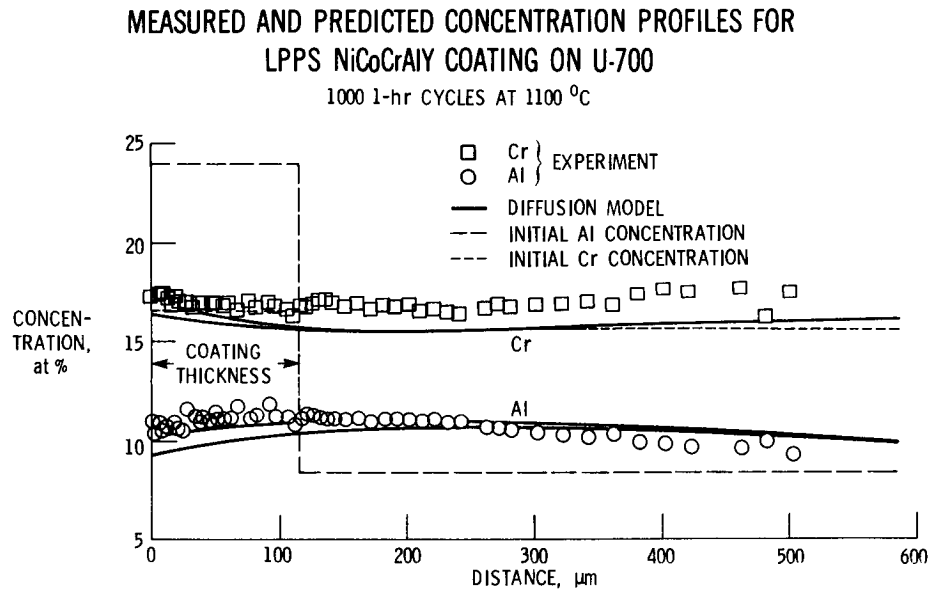

Figure 7

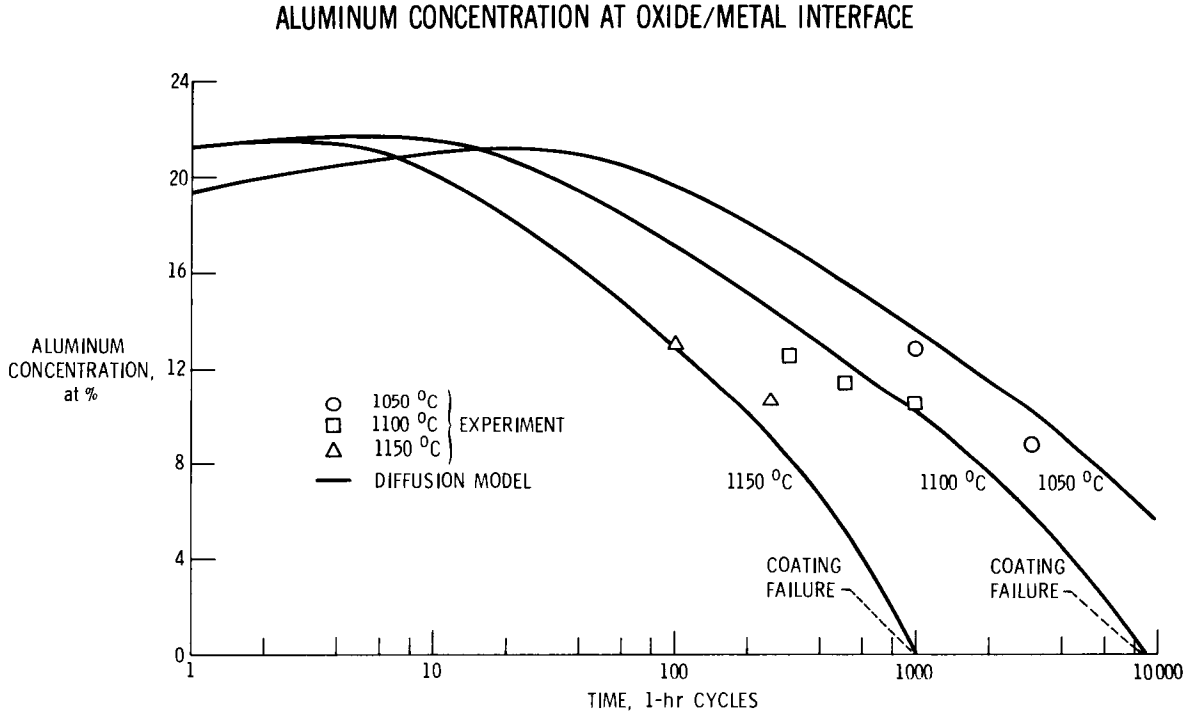
ALUMINUM CONCENTRATION AT OXIDE/METAL INTERFACE
ALUMINUM CONCENTRATION, at %
24
20
16
12
8
4
0
1
10
100
1000
10000
TIME, 1-hr CYCLES
1050 °C
1100 °C
1150 °C
EXPERIMENT
DIFFUSION MODEL
1150 °C
1100 °C
1050 °C
COATING FAILURE
COATING FAILURE

Figure 8