N88-11180

Effects of Surface Chemistry on Hot Corrosion Life*

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This program has as its primary objective the development of hot corrosion life prediction methodology based on a combination of laboratory test data and evaluation of field service turbine components which show evidence of hot corrosion. The laboratory program comprises burner rig testing by TRW. The discussion will summarize the results of two series of burner rig tests and outline the life prediction methodology parameters to be appraised in a final campaign of burner rig tests.

The two completed burner rig hot corrosion tests were performed under identical conditions, as given in Table 1. Specimens included U700 and Rene'80, uncoated and with the following coatings.

- o RT21 aluminide (Chromalloy American Corp.)
- o Codep aluminide (General Electric Co.)
- o Ni23Co18Cr12Al0.3Y applied by vacuum (low pressure) plasma spraying

At approximately twenty cycle intervals, specimens were visually examined, photographed, and coil inductance measurements made in a series mode at 10MHz with a multifrequency LCR meter. These measurements, which are patterned after studies at NASA-LeRC, afford a non-destructive means of following the course of metal degradation. Ultimately the inductance data bank from this program will be useful in the interpretation of the extent of oxidation/hot corrosion phenomena, in particular subtle differences between materials.

Specimens were considered to have failed when visual evidence of hot corrosion was noted in three successive inspections. Subsequent metallographic evaluation has confirmed substantial Type 1 sulfidation for all the uncoated specimens and, in most cases, coating penetration for the coated specimens.

In the first series of hot corrosion tests, duplicate as-fabricated specimens were exposed. In the second series of tests, specimens (coated alloys only) were exposed which had been preaged at 1100C under a variety of conditions to determine the effect on hot corrosion behavior caused by surface oxidation and/or interdiffusion between coating and substrate alloy. The aging conditions were:

* Contract NAS3-23926

- o One hour cyclic, static air — 100 hours
- o One hour cyclic, burner rig — 100, 300, 600 hours
- o isothermal, static air — 100, 300, 600 hours
- o isothermal, vacuum — 100 hours

Triplicate specimens were aged; one withheld for metallographic evaluation and the remaining duplicates exposed in the hot corrosion tests.

In the baseline hot corrosion test, results in general were consistent with previous experience.

- o Uncoated U700 corroded at about twice the rate of uncoated Rene'80, paralleled by a similar difference in coil inductance changes as reported at the 1984 Workshop.

- o Coatings lives were similar on both substrates, i.e.

  - 424 to 602 hours for Codep coated specimens.
  - $\geq$ 1000 hours for NiCoCrAlY coated specimens.

On the other hand the RT21 coating which is compositionally similar to Codep survived longer than Codep in this test: the coating was failed in two specimens at 697 and at 1005 hours, but not completely penetrated in two other specimens at 997 and at 1005 hours. A difference between these coatings also was apparent in the coil inductance changes as was reported at the 1984 Workshop. Detailed electron microprobe analyses failed to reveal any significant compositional differences between the two coatings and both have the structural features of inward aluminide coatings. However the RT21 coating showed some evidence of entrapment of small oxide particles in the outer 5μm while the Codep coating did not. Whether this difference is the cause of differences in hot corrosion lives cannot be concluded with certainty; yet it may be noted that, as will be shown, no consistent difference in life exists for specimens preaged at 1100C.

Before discussing the results of the second series of hot corrosion tests some comments are required about preaging. In furnace exposures even up to 600 hours there was frequently localized pitting but no examples of coating failure. However in burner rig preaging localized pitting was significantly more severe and approached penetration in a few instances even at 100 hours. For the longer exposures coating penetration was often observed. Since coatings on the specimens preaged in the burner rig for 300 hours or more had essentially failed during that time, their hot corrosion lives are of minimal value and will not be discussed.

Limiting the results in this manner it became clear that preaging caused substantial decreases in coatings lives relative to the baseline results cited above, particularly for the aluminides (RT21 and Codep). What is most striking (see Figure 1) is that for all three coatings life degradation is far more severe for coated U700 than for coated Rene'80. This cannot be attributed to metal recession during the preaging which was minimal in 100 hours in air and zero in vacuum. It is interesting to note that on average the consequences of preaging in vacuum and in air appear to be similar. This suggests (as will be discussed below) that compositional changes resulting from coating/substrate interdiffusion predominate over surface oxidation in affecting subsequent hot corrosion performance.

As shown in Figure 2 coatings lives for some coating/substrate systems degrade progressively from 100 to 600 hours preoxidation; while for other systems maximum degradation has occurred in 100 hours preoxidation.

In an attempt to explain the large and consistent differences in the coated U700 and Rene'80 specimens, quantitative electron microprobe analyses of coatings were obtained on selected specimens in the as-preaged condition (prior to hot corrosion testing). Within measurement error, Codep and RT21 compositions were indistinguishable for a given preage time as were those at 100 hours oxidation whether isothermal, furnace cyclic or burner rig cyclic. Data thus consolidated are given in Table II.

- For both aluminide and NiCoCrAlY coatings there are no apparent major differences between the U700 and Rene'80 systems.

- For both aluminide and NiCoCrAlY coatings there are no significant differences between vacuum and air preaging, reinforcing the above comment that interdiffusion effects are far more important than surface oxidation in determining subsequent hot corrosion coating life.

- The composition changes for the aluminide coatings are much greater (especially Al content) than for the NiCoCrAlY coating. This parallels the differences in hot corrosion life shown in Figures 1 and 2. Note also coil inductance changes (Figure 3) for cyclic oxidation preaging which parallel the lesser composition changes for the NiCoCrAlY coated specimens. Here again there is no hint as to reasons for differences in the coated U700 and Rene'80 systems.

The data in Table II represent average compositions of the coating additive layer. Another aspect to consider is the makeup of the diffusion zone (in particular for aluminide coatings) since prior experience suggests that while beta NiAl corrodes rather rapidly, the rate slows down when the diffusion zone is reached. Conceivably the makeup of the diffusion zone is equivalent in a corrosion sense for aluminide/U700 and aluminide/Rene'80 systems in the as-fabricated condition but changes in different manners (or rates) in the 1100C preaging. There are, in fact, visual differences after aging which did not exist before aging. Before aging, the diffusion zone in both systems contains a closely spaced needle like phase (sigma) in a beta matrix, oriented normal to the surface. As aging at 1100C progresses this phase gradually disappears and a blocky phase (carbides) forms. The rate of this transformation is considerably faster for the U700 system and is nearly complete in 100 hours. Further investigation of these differences is planned and will be factored into life prediction modeling in the remainder of this program.

The rationale for life prediction modeling and confirmatory hot corrosion testing is as follows. Since in the mission of an aircraft engine, a small percentage of time is spent at turbine temperatures considerably higher than cruise (takeoff and thrust reverse, analogous to the 1100C aging in this program), coating/substrate interdiffusion with consequent accumulative decrease in remaining coating life can take place. A series of age treatments followed by hot corrosion tests will provide input for one element in mission analysis/life prediction. For an aircraft flying short missions, high temperature operation will accumulate faster in terms of total flying hours and hot corrosion coating life would be expected to be less based on the results discussed above. Such a correlation was qualitatively apparent in the analysis of field service turbine components performed earlier in this program, as reported at the 1984 Workshop.

It is clear that a life prediction model must include not only mission analysis and coating identification but substrate identification as well.

To have maximum opportunity to vary aging times (and test conditions) within the scope of planned tests, the remaining burner rig tests will be limited to Codep coated U700 and Codep coated Rene'80. Aging will be limited to isothermal oxidation. In the first of these tests, now underway under the conditions given in Table I, preaging times of 15 and of 25 hours are included. Evaluation will include detailed electron microprobe analyses of as-aged specimens and further consideration of possible differences in the diffusion zone between the two substrate systems. Further tests will include additional aging times and/or different salt levels.

Table I Burner Rig Operating Conditions.

Specimen Temperature - 900° C ± 9° C

Test Cycle - 1 hour at temperature followed by 6 minutes of forced air cooling

Sodium Concentration - 0.5 ppm sodium (±10%) in the combustion gases introduced as aqueous NaCl

Combustion Air Preheat Temperature - 232° C ± 10° C

Specimens - Eight positioned equally on a 4.2 cm (1.64 inch) diameter circle of a holder rotating at 600 rpm

Burner Nozzle Throat Diameter - 2.54 cm (1.0 inch)

Burner Pressure - [illegible].0 psig

Nozzle Throat to Nearest Specimen - 4.45 cm (1.75 inch)

TABLE II Average Compositions of Coating Additive Layer as Function of Aging Time at 1100C (Weight Percent)

Aluminide	Age, Hours	*	Al	Cr	Mo	Ti	Co	Ni
Rene'80	0	2	31	5	0.6	0.7	6	52
	100 Vacuum	2	18	7	0.4	3.8	9	62
	100 Oxidation	2	18	6	0.2	3.4	9	63
U700	0	2	31	5	0.6	0.8	10	52
	100 Vacuum	1	17	7	0.6	3.1	12	61
	100 Oxidation	3	18	7	0.6	2.9	13	61
NiCoCrAlY								
Rene'80	0	1	13.0	20		0.2	19	43
	100 Vacuum	1	11.0	14	0.7	1.7	19	53
	100 Oxidation	2	11.3	16	0.6	1.8	17	54
	600 Oxidation	1	7.8	19	1.3	2.5	16	54
U700	0	1	12.0	20		0.4	21	44
	100 Vacuum	0		Not Analyzed				
	100 Oxidation	2	12.8	15	0.3	1.6	19	54
	300 Oxidation	1	7.4	17	1.9	2.6	19	55
	600 Oxidation	1	7.5	17	1.9	2.2	19	54

*Entries in this column are numbers of specimens analyzed.

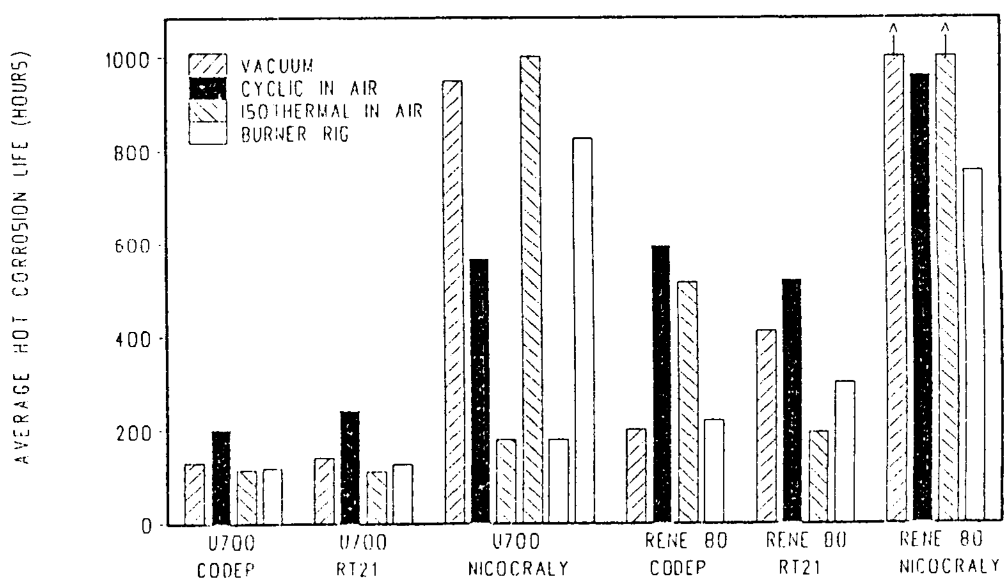

Figure 1 Hot corrosion coating life at 900C after 100 hours preaging at 1100 C. (Each bar is an average for two specimens except for NiCoCrAlY coated U700, isothermal and burner rig, for which individual results are shown).

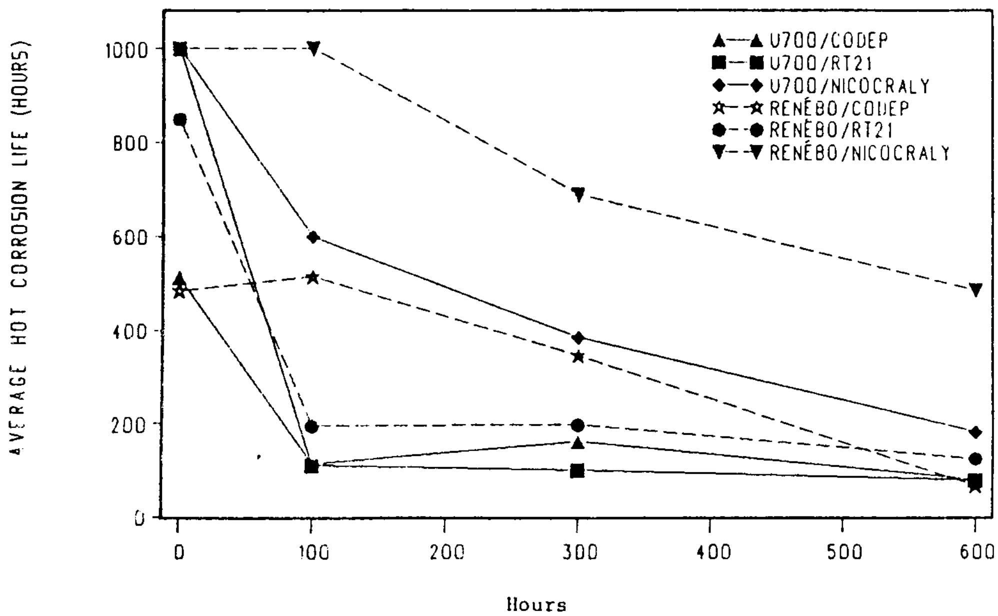

Figure 2 Hot corrosion life at 900C versus isothermal preaging time at 1100C.

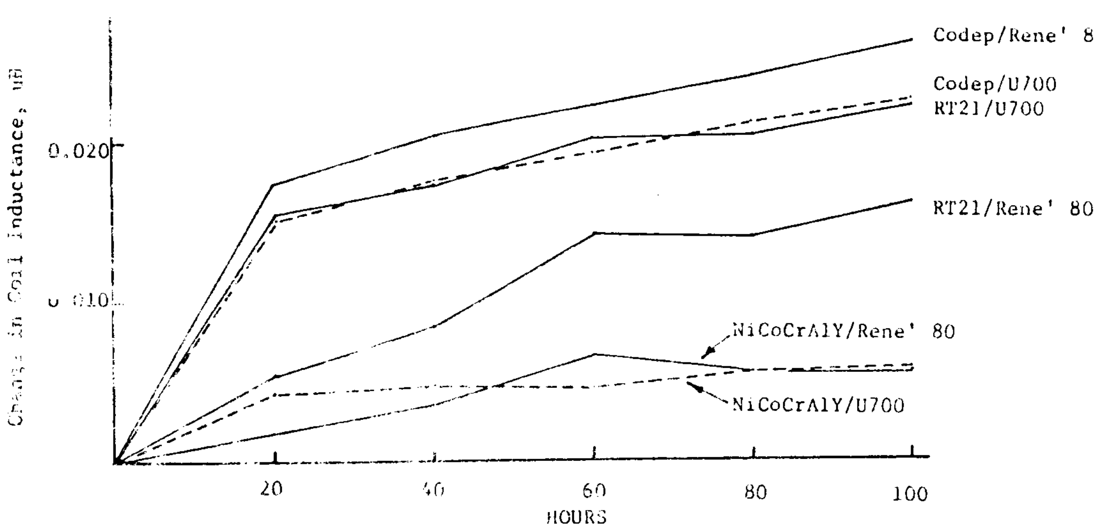

Figure 3. Changes in Coil Inductance in Static Oxidation at 1100C, Cyclic Exposure.