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16. Abstract

Several oxide dispersion strengthened (ODS) alloys were tested for cyclic, high velocity, oxidation and hot corrosion resistance. These results were compared to the resistance of an advanced, NiCrAl coated superalloy. An ODS NiCrAl and an ODS FeCrAl were identified as having sufficient oxidation and hot corrosion resistance to allow potential use in an aircraft gas turbine without coating.

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SUMMARY

High velocity, cyclic oxidation tests were conducted on several uncoated ODS alloys at 1100° C for times to 3000 hours. Oxidation resistance of these materials was compared to that of MM200 coated with an advanced NiCrAl coating. The alloys evaluated were a FeCrAl (MA-956), NiCrAl with Fe (MA-953) and two NiCrAls (HA-8077 and HA-8077 modified with additional Al). The MA-956 and HA-8077 had oxidation resistance comparable to the coated superalloy while the modified HA-8077 was slightly less resistant and the MA-953 was much less resistant to oxidation than any of the other alloys. All but the MA-953 were judged sufficiently oxidation resistant for use as aircraft gas turbine vanes in applications involving maximum metal temperatures of 1100° C.

The same alloys plus tantalum-modified HA-8077 were tested in an accelerated high velocity, hot corrosion test at 900° C. MA-956 was more corrosion resistant than any other material tested including the coated MM200. HA-8077 and HA-8077 with additional Al were less resistant to hot corrosion than the coated MM200 but still were exceptionally good. The tantalum-modified alloys and MA-953, while substantially better than conventional superalloys, were much less resistant than the NiCrAls without tantalum or iron. These results suggest that hot corrosion should not limit life (at least to 3000 hr) of the NiCrAls or the FeCrAl in aircraft turbine applications.

INTRODUCTION

Several oxide dispersion strengthened (ODS) alloys have been developed with potential for use as aircraft turbine vanes at temperatures to 1100° C. (Oxidation and hot corrosion test results are given in ref. 1.) This work indicated that Y_2O_3 strengthened NiCrAls had excellent oxidation and hot corrosion resistance in short time (~200 hr) tests. Other work (ref. 2) indicated that a Y_2O_3 strengthened FeCrAl had even more promise in oxidation/hot corrosion but was questionable in terms of having sufficient high temperature strength. The purpose of this work was to determine the oxidation resistance of these and other ODS alloys for times to 3000 hours

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at 1100° C. Also evaluated was the hot salt corrosion resistance of these alloys at 900° C for times to 2000 hours. All samples were tested cyclically in a Mach 0.3 burner rig. The resistance of the alloys was judged by change in weight (Δw), metal thickness loss (Δt), and metallography. The alloys investigated were primarily ODS NiCrAls with and without quaternary additions and an ODS FeCrAl. A commercial superalloy (MM-200) with an advanced NiCrAl coating was tested simultaneously for comparison.

MATERIALS AND PROCEDURES

The alloys tested in this program and their compositions are listed in table I. HA-8077 is a commercial ODS NiCrAl while AT-264, AT-265, and AT-266 are modifications of HA-8077, AT-264 has slightly more aluminum than HA-8077 and was identified as superior to it in reference 1. AT-265 and AT-266 are nominally the same composition as AT-264 except that they contain tantalum. MA-953 is an La_2O_3 strengthened NiCrAl with 35 w/o iron added while MA-956 is basically an ODS FeCrAl. All of these alloys were received in the as-extruded and hot worked condition. They were machined to the shape shown in figure 1. The NiCrAl coated MM-200 samples were received from a commercial vendor. All samples were weighed to ±0.2 milligram (mg) and their diameters measured to ±1 micrometer (μm).

The burner rig used for these tests is shown in figure 2; it has been fully described in several reports from this laboratory (e.g., ref. 3). The oxidation tests were run with JP-5 fuel combusted and expanded through the nozzle at Mach 0.3. Each cycle consisted of 1 hour in the flame at 1100° C metal temperature followed by a 3-minute cooling in forced air. The samples were weighed once a day. Oxidation samples were run until failure (loss of >50 mg/cm^2) or ~3000 cycles. After removal from test each sample was photographed, sectioned (A-A in fig. 1), and mounted for metallography. Unaffected metal thickness was measured with a traveling microscope for a determination of thickness change, Δt. All samples were run in duplicate.

Hot corrosion tests were conducted in the same type of rig using the same duty cycle but with a temperature of 900° C. A water solution of synthetic sea salt (see table II for its composition) was added to the combustion products in the combustion chamber to a level of 5 parts per million by weight of combustion air. After every 15 cycles the samples were weighed, washed in distilled water and weighed again. As in the oxidation tests samples were removed after their washed weight had reached ~ -50 mg/cm^2 and were then photographed, sectioned, and metallographically mounted for Δt measurements and microstructural evaluation.

RESULTS AND DISCUSSION

Oxidation

Because of the longer times to failure, fewer alloys were tested in oxidation than in hot corrosion. The ΔW data are plotted in figure 3 along with some burner rig data on TD-NiCr (ref. 4) for comparison. MA-953 was the first alloy to fail (600 - 800 cycles). Surprisingly (in light of ref. 1), the modified HA-8077 (AT-264) was less oxidation resistant than the unmodified HA-8077 (AT-259) sample. Indeed, HA-8077 (AT-259) showed only 10 mg/cm^2 loss at the conclusion of the test (3000 cycles). The ODS FeCrAl (MA-956) showed little evidence of attack (~2 mg/cm^2) even at 3790 cycles. There was a slight weight gain (2 mg/cm^2) on the coated MM-200 at 3790 cycles.

The appearance of the alloys, as shown in figure 4 confirms the impression received from ΔW data except in the case of the coated alloy. The coating on one of the two duplicates showed substantial coating failure due to pitting. Even though at the conclusion of the test the coated samples showed little weight change, it is obvious that the coating has little life left. Further confirmation is given by the metallography in figure 5. Except for a small recrystallized zone at the surface, the ODS FeCrAl shows little evidence of the prolonged oxidation exposure. The HA-8077 (AT-259) looks as good as the ODS FeCrAl except for some void formation. Both the MA-953 and the AT-264 (modified HA-8077) show extensive oxide penetration, while the coated MM-200 showed isolated oxide penetration of the coating.

The Δt data in table III(a) are still further confirmation of the results. Both the MA-953 and the modified HA-8077 show substantial metal loss while the HA-8077 (AT-259) had only minor metal recession and the Δt measured on the ODS FeCrAl was at the limit of detection. It should be noted that all of the alloys with the possible exception of MA-953 were shown to have excellent oxidation resistance when compared to most uncoated superalloys.

Hot Corrosion

The ΔW data for the hot corrosion tests are plotted in figure 6. This is an accelerated test as can be seen from the data for IN-792 (ref. 3) which is plotted for comparison. This alloy is generally considered to have relatively good hot corrosion resistance, but under the conditions of this test its life is less than 150 hours. The alloys tested here fell into three groups in terms of hot corrosion life. The least resistant were MA-953 and the two tantalum modifications of HA-8077 (AT-265 and AT-266). Their lives were about 400 hours. Substantially more resistant were the

ODS NiCrAls without tantalum (HA-8077 and aluminum modified HA-8077 (AT-264). Their lives were about 1100 hours with the unmodified alloy life being slightly longer. Finally, the ODS FeCrAl showed no indication of failure after 2313 cycles. The coatings on MM-200 failed locally after approximately 1200 hours.

The appearance of the samples (fig. 7) and their metallography (fig. 8) confirm that the samples had indeed failed by the conclusion of their test time. The single exception was ODS FeCrAl which showed no external or microstructural evidence of even having been in test. More confirmation is shown by this Δt data in table III(b). As in the oxidation tests the Δt for ODS FeCrAl is the same as the error in the measurement.

As in the case of the oxidation data, it must be stressed that all the alloys tested are excellent in hot corrosion when compared to conventional bare superalloys. In fact the ODS FeCrAl and the two ODS NiCrAls without quaternary additions probably have enough hot corrosion life for vane service in most aircraft turbines.

CONCLUDING REMARKS

As a result of high velocity cyclic testing for oxidation at 1100° C and hot corrosion at 900° C, several observations can be made. In general, uncoated ODS NiCrAls and ODS FeCrAl have sufficient oxidation resistance for long time service at a metal temperature of 1100° C. They also have excellent hot corrosion resistance; the limits of ODS FeCrAl were not reached in this study. It remains to be demonstrated whether or not these alloys have sufficient high temperature strength and thermal fatigue resistance for vane applications. If they do have the latter properties, these alloys could find use not only in aircraft gas turbines but also in ground power turbines as well. These tests also indicate a great potential of FeCrAl alloys for hot corrosion resistance which might be realized by using such compositions for coating or cladding.

REFERENCES

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2. Whittenberger, J. D.: Creep and Tensile Properties of Several Oxide-Dispersion-Strengthened Nickel-Base Alloys at 1365 K. NASA TN D-8422, 1977.

3. Lowell, Carl E.; and Deadmore, Daniel L.: Effect of a Chromium-Containing Fuel Additive on Hot Corrosion. NASA TM X-73465, 1976.

4. Johnston, James R.; and Ashbrook, Richard L.: Oxidation and Thermal Fatigue Cracking of Nickel- and Cobalt-Base Alloys in a High Velocity Gas Stream. NASA TN D-5376, 1969.

TABLE I. - ALLOY ANALYSIS IN WEIGHT PERCENT

Element	AT-259 (HA-8077)	AT-264	AT-265	AT-266	MA-953[a]	MA-956
Al	4.17	4.54	4.7	4.9	5.5	4.40
Cr	15.7	15.7	16.0	15.9	21	18.9
Ni	Bal.	Bal.	Bal.	Bal.	Bal.	0.4
Fe	----	----	----	----	35	Bal.
Ta	----	----	1.7	1.2	---	----
Y[b]	1.6	1.5	1.5	1.5	---	0.7
Co	----	1.10	0.7	0.4	---	----
Ti	----	----	----	----	0.5	0.5
C	0.06	0.05	0.05	0.05	---	0.02
La[c]	----	----	----	----	0.3	----

[a]Nominal values.
[b]Present as Y_2O_3.
[c]Present as La_2O_3.

TABLE II. - COMPOSITION OF SYNTHETIC SEA SALT

Compound	Concentration, g/l
NaCl	24.53
$MgCl_2$	5.20
Na_2SO_4	4.09
$CaCl_2$	1.16
KCl	.695
$NaHCO_3$	.207
KBr	.101
H_3BO_3	.027
$SrCl_2$	.025
NaF	.003

TABLE III. - METAL THICKNESS LOSS

[All values are ±0.01 mm.]

(a) Oxidation

Alloy	Cycles	Thickness change, Δt, mm
AT-259 (HA-8077)	3000	0.02
AT-264	2993	.86
MA-953	787	.40
MA-956	3790	.01

(b) Hot corrosion

AT-259 (HA-8077)	1119	0.32
AT-264	1220	.50
AT-265	504	.45
AT-266	435	.44
MA-953	415	.19
MA-956	2313	.01
IN-792	100	.64

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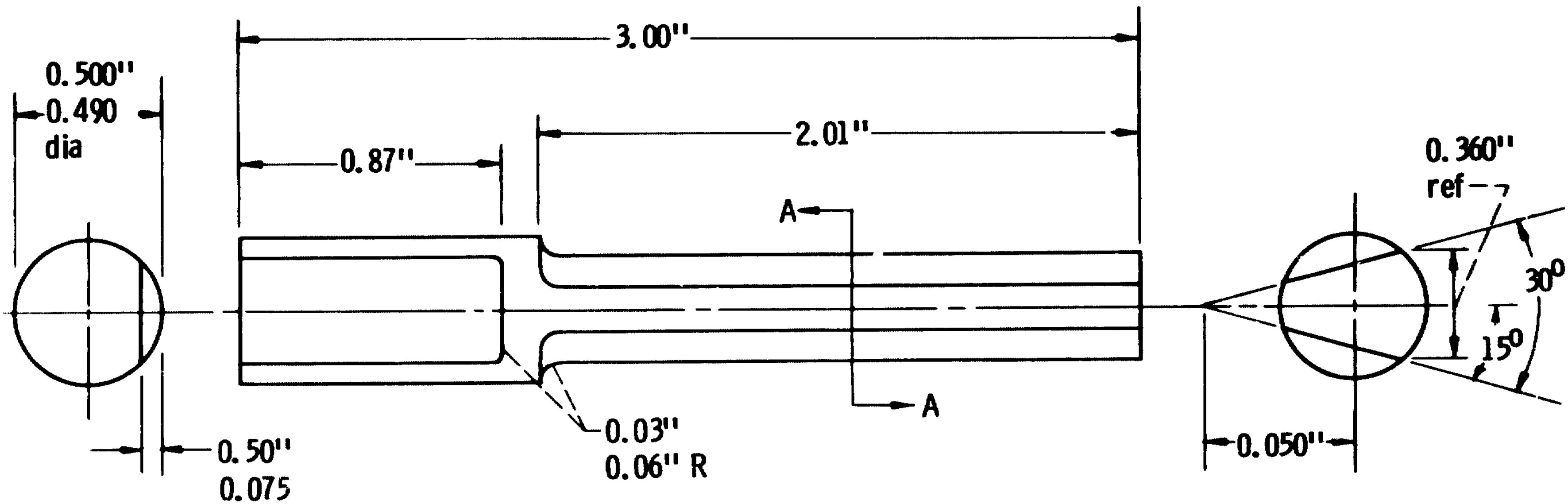


Figure 1. - Burner rig sample geometry.

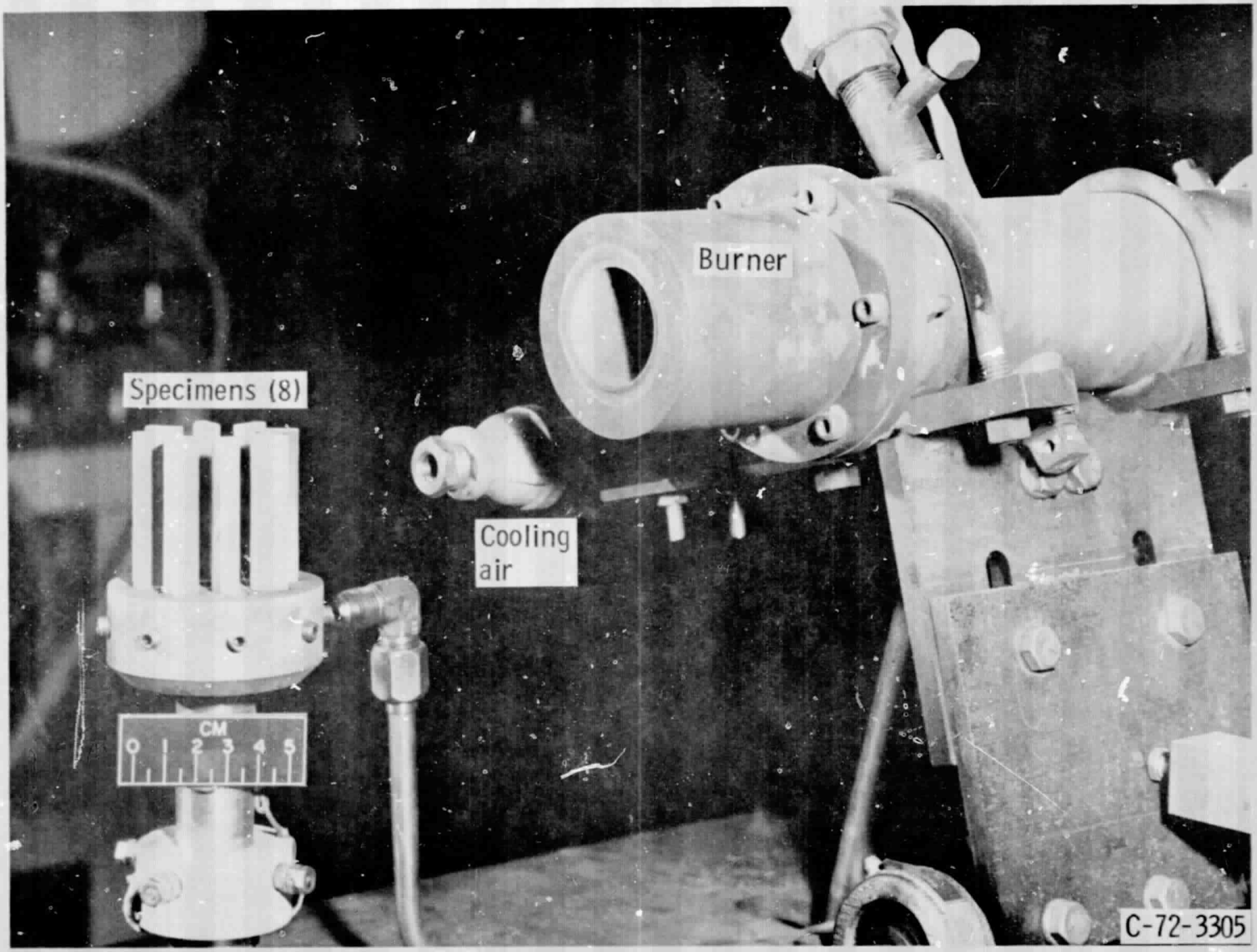


Figure 2. - Mach 0.3 oxidation apparatus.

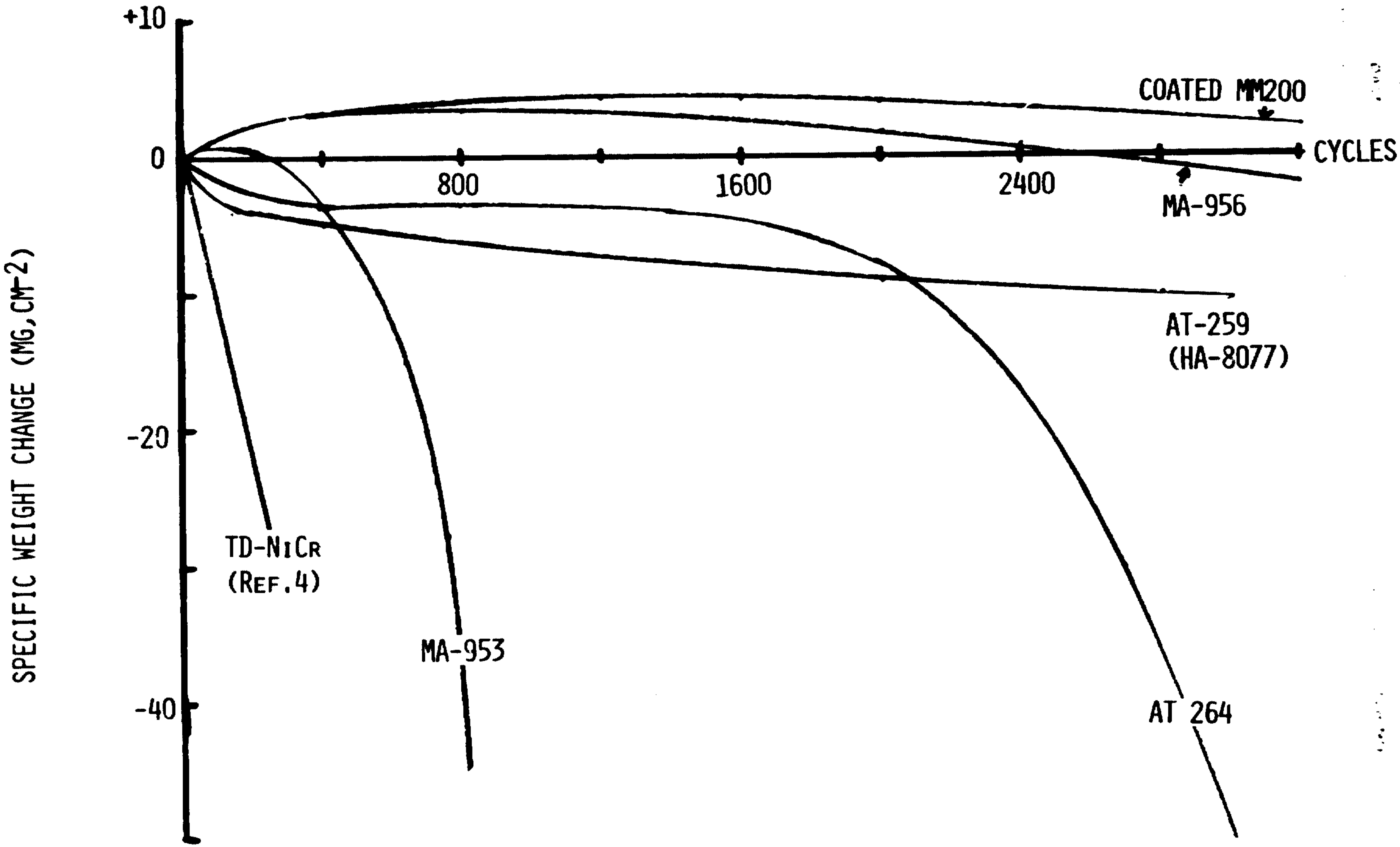


FIGURE 3. MO.3 CYCLIC OXIDATION OF SOME OXIDE DISPERSION STRENGTHENED ALLOYS AT 1100°C. ONE HOUR AT TEMPERATURE PER CYCLE.

MA956
3790 CYCLES

MA953
787 CYCLES

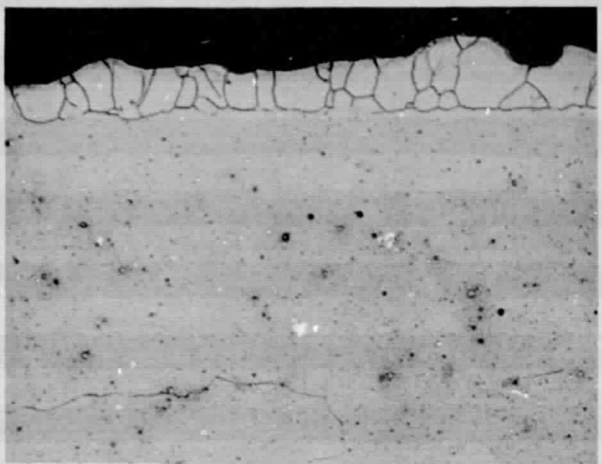
AT-259 (HA-8077)
3000 CYCLES

AT-264
2993 CYCLES

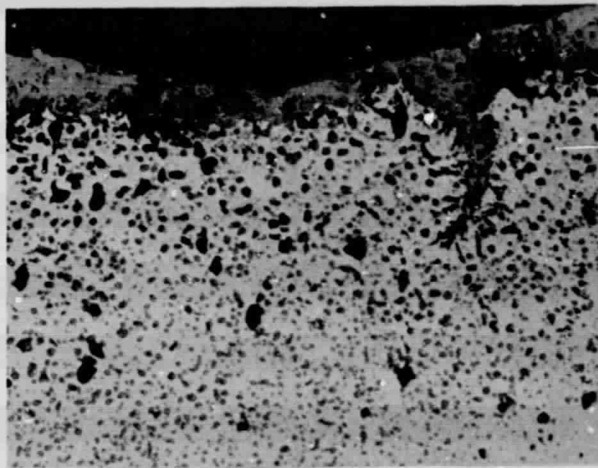
NiCrAlY COATED MM-200
3790 CYCLES

1CM

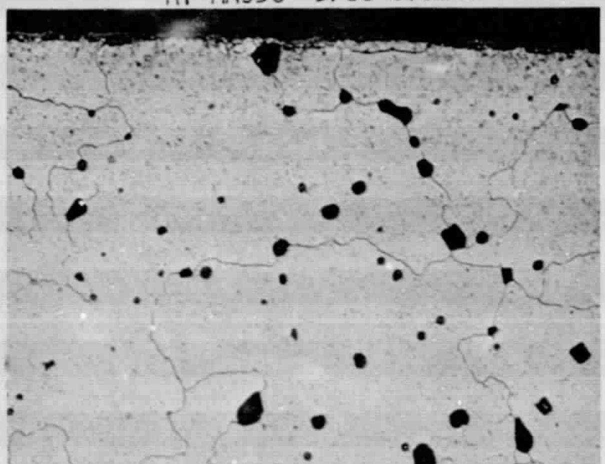
FIGURE 4. SURFACE DAMAGE OF SOME OXIDE DISPERSION STRENGTHENED ALLOYS AFTER CYCLIC OXIDATION AT 1100°C IN A MO.3 GAS STREAM. ONE HOUR AT TEMPERATURE PER CYCLE. APPROXIMATELY FULL SIZE.



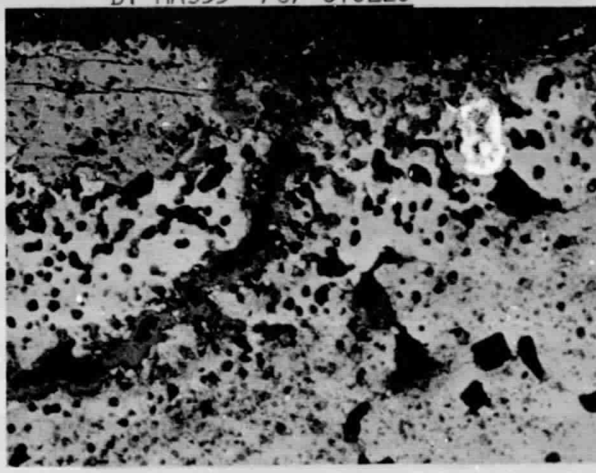
A. MA956 3790 CYCLES



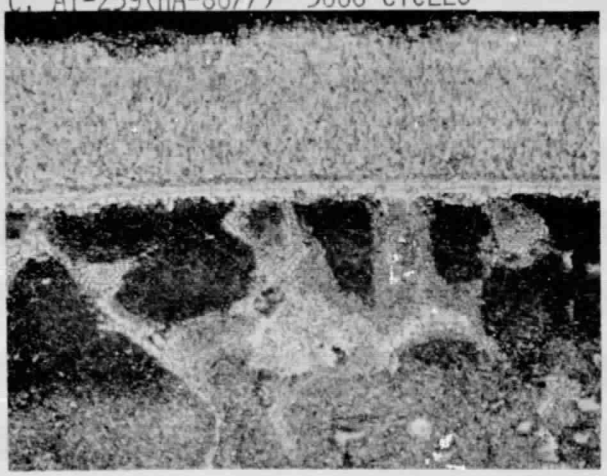
B. MA953 787 CYCLES



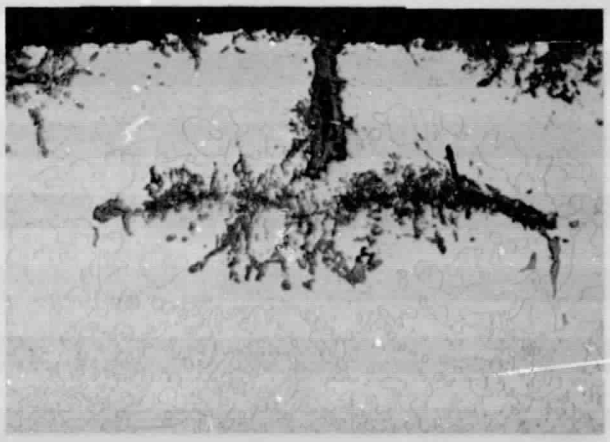
C. AT-259(HA-8077) 3000 CYCLES



D. AT264 2993 CYCLES



E. NiCrAlY COATED MM200 AS RECEIVED



F. NiCrAY COATED MM200 3790 CYCLES

FIGURE 5. THE EFFECT OF MO.3 OXIDATION ON THE SURFACE & MICROSTRUCTURE OF SOME OXIDE DISPERSION STRENGTHENED ALLOYS. ONE HOUR AT 1100°C PER CYCLE. MAGNIFICATION - 250X

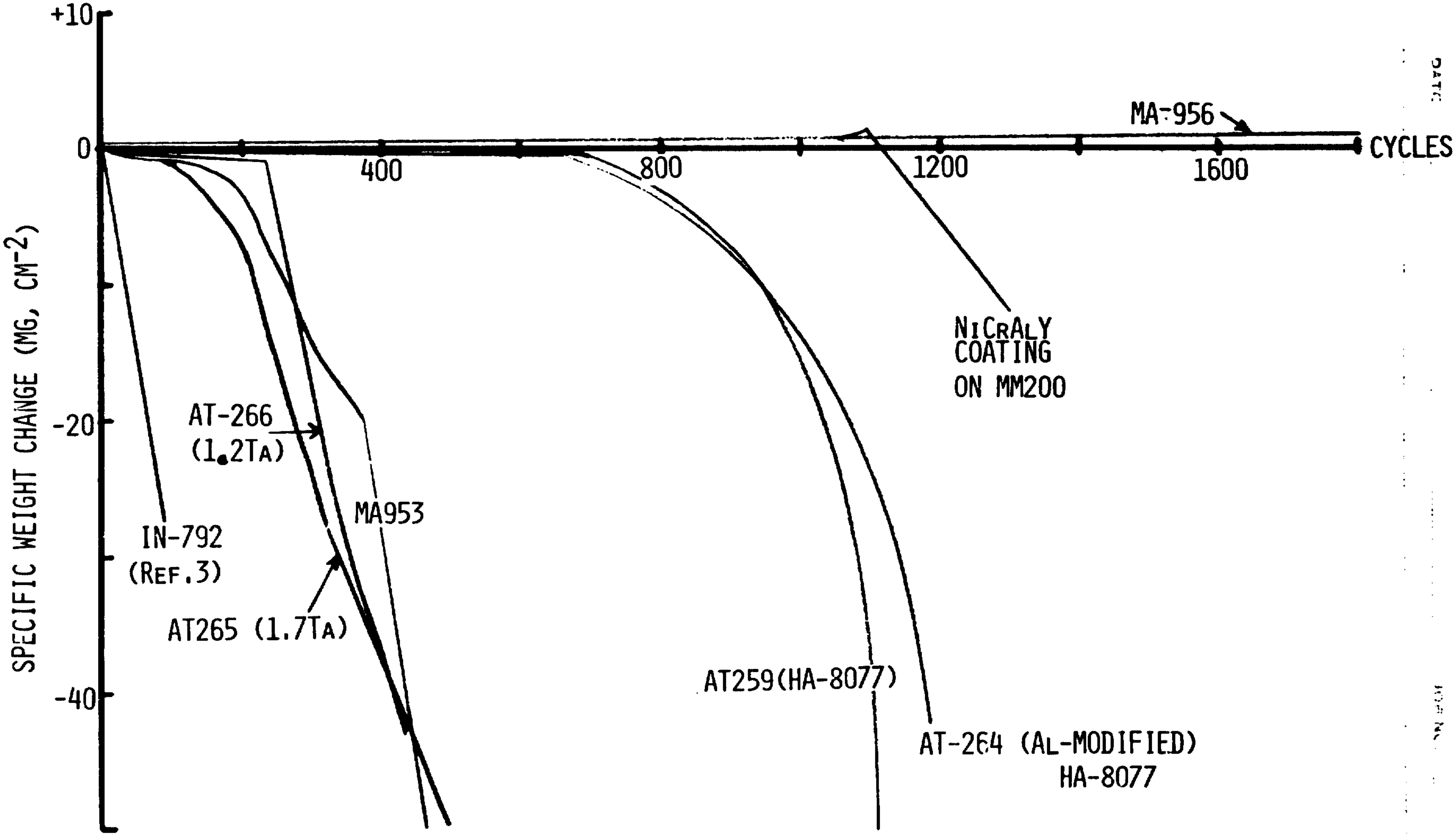
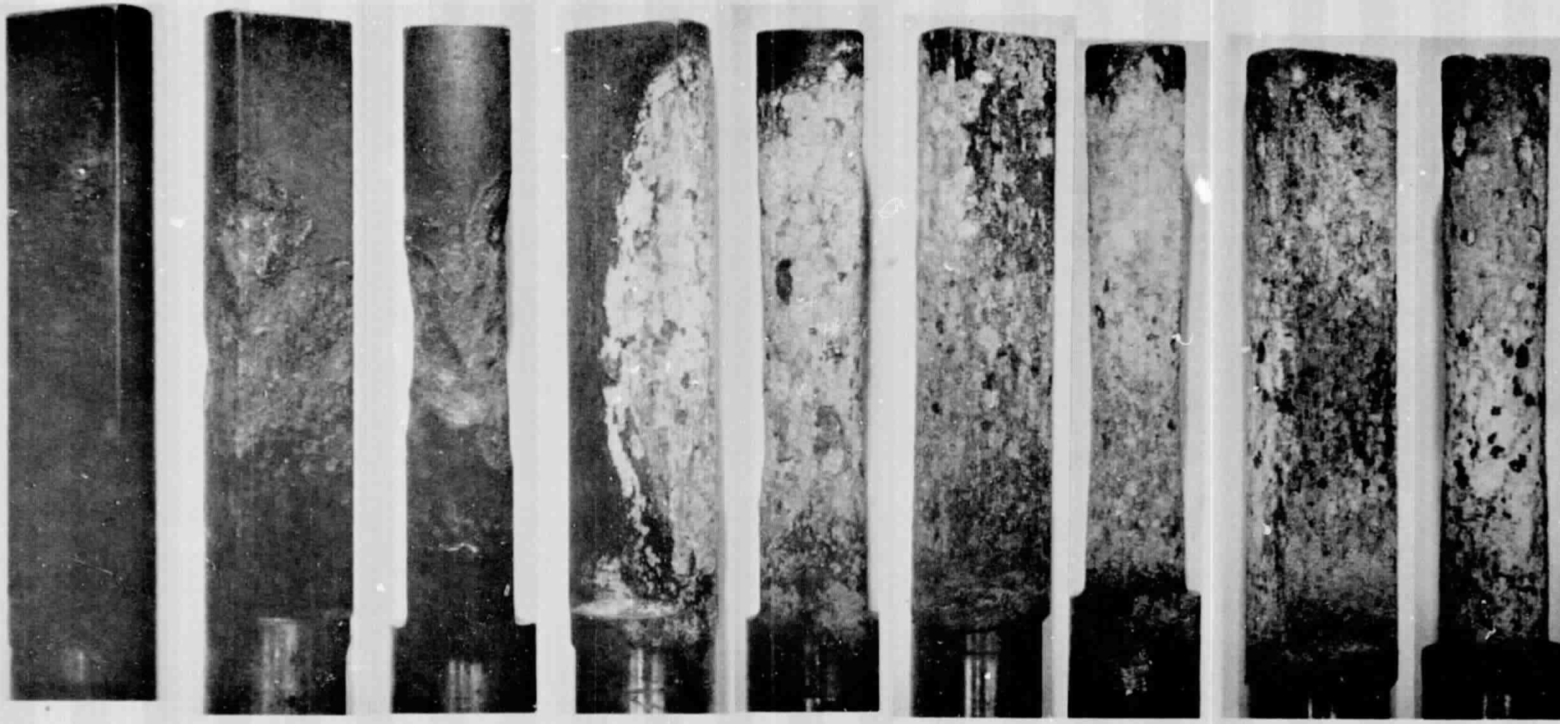


FIGURE 6. HOT CORROSION OF SOME OXIDE DISPERSION STRENGTHENED ALLOYS AS COMPARED TO A NiCrAlY COATING AND A TYPICAL Ni-BASE SUPERALLOY. ONE HOUR AT 900°C PER CYCLE, 5PPM SYNTHETIC SEA SALT



MA956
2313 CYCLES

MA953
415 CYCLES

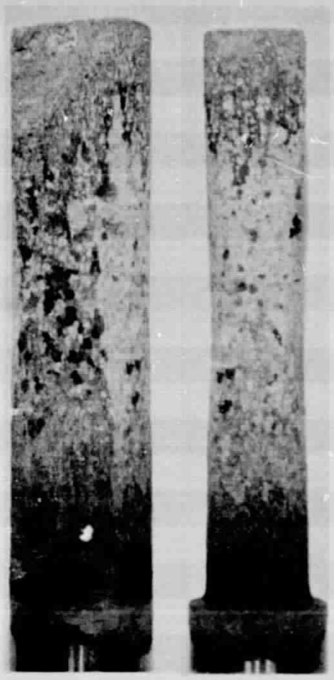
AT-259(HA8077)
1119 CYCLES

AT-264
1220 CYCLES

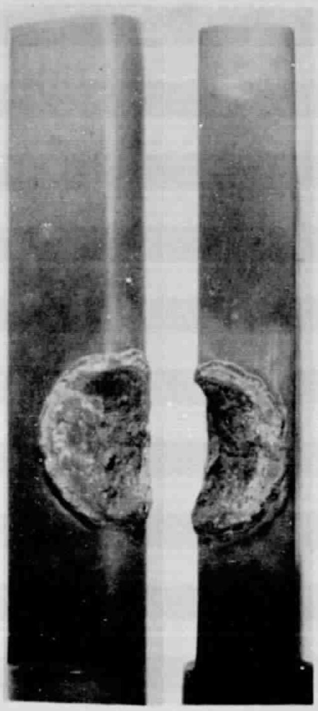
AT-265(1.7Ta)
504 CYCLES

1CM

FIGURE 7. SURFACE ATTACK OF SOME OXIDE DISPERSION STRENGTHENED ALLOYS AFTER CYCLIC HOT CORROSION, 5PPM SALT, AT 900°C, M0.3, ONE HOUR AT TEMPERATURE PER CYCLE. APRROXIMATELY FULL SIZE.

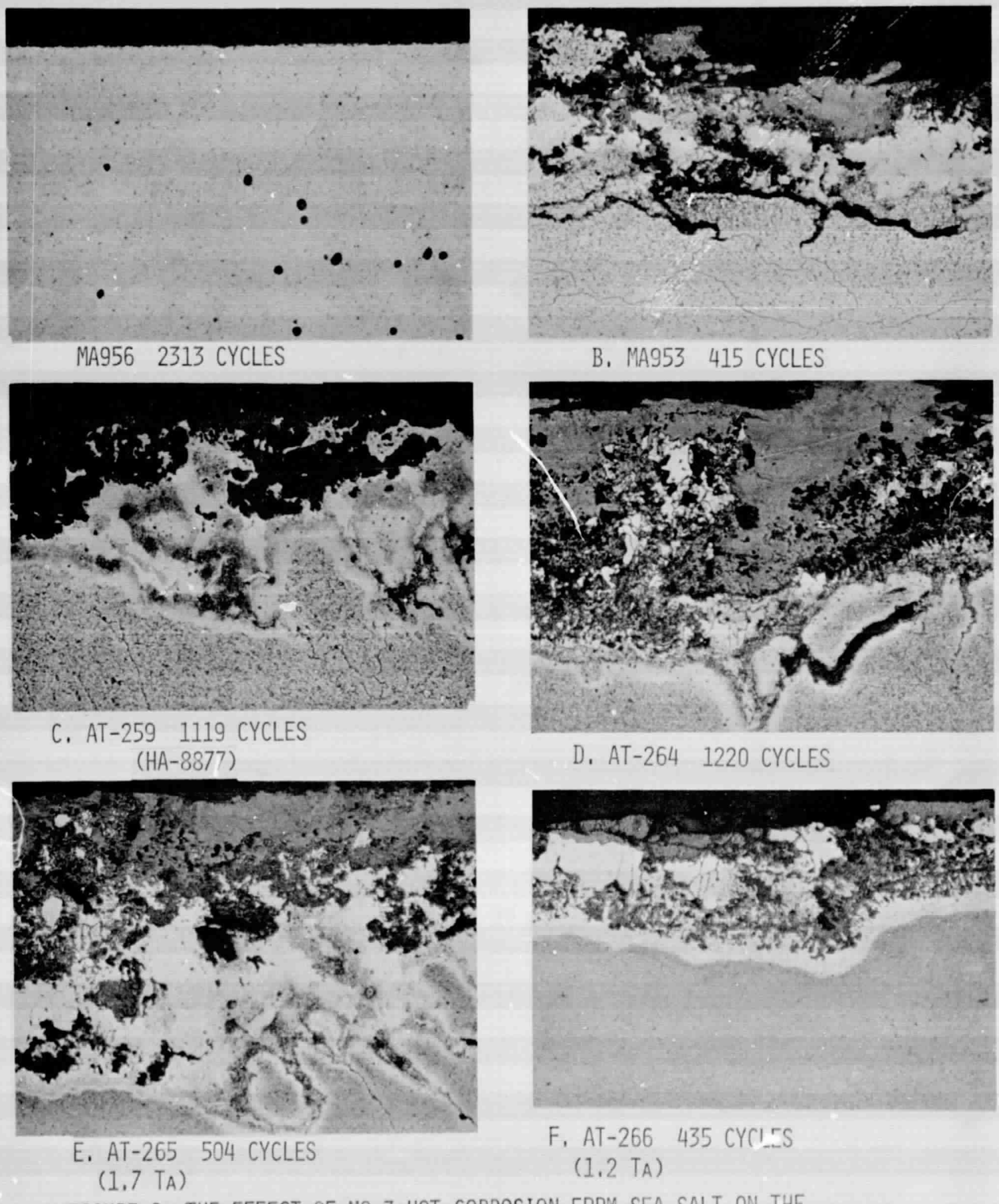


AT-266 (1.2Ta)
435 CYCLES



NiCrAlY COATED
NM200 1429 CYCLES

FIGURE 7 Continued



MA956 2313 CYCLES

B. MA953 415 CYCLES

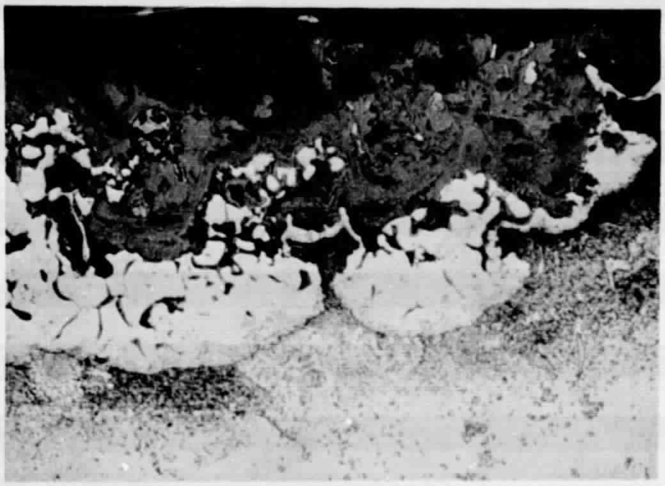
C. AT-259 1119 CYCLES (HA-8877)

D. AT-264 1220 CYCLES

E. AT-265 504 CYCLES (1.7 TA)

F. AT-266 435 CYCLES (1.2 TA)

FIGURE 8. THE EFFECT OF MO.3 HOT CORROSION, 5PPM SEA SALT, ON THE MICROSTRUCTURES OF SOME OXIDE DISPERSION STRENGTHENED ALLOYS AT 900°C. ONE HOUR AT TEMPERATURE PER CYCLE. 250X. ETCHED



G. NiCrAlY COATED MM-200 1429 CYCLES

FIGURE 8. Continued