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EVALUATION OF NiCrAl AND FeCrAlY CLADDINGS ON TD-NiCr: MACH 1 BURNER RIG TESTS AT 2100° F (1149° C)

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This information is being published in preliminary form in order to expedite its early release.

ABSTRACT

Foils, of several oxidation resistant alloys approximately 5 mils (0.127 mm) thick, were diffusion bonded to TD-NiCr. The protection potential of these claddings for use on aircraft gas turbine components was examined by conducting Mach 1 burner rig tests at 2100° F (1149° C) for times to 160 hours using 1 hour cycles. The NiCrAl cladding was protective for over 120 hours. All of the FeCrAlY alloys, however, began suffering from oxidation and loss of cladding after 20 to 40 hours of testing. Visual indications of interdiffusion were observed in TD-NiCr for both cladding systems.

EVALUATION OF NiCrAl AND FeCrAlY CLADDINGS ON TD-NiCr:

MACH 1 BURNER RIG TESTS AT 2100° F (1149° C)

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E-6021

SUMMARY

This study examined the ability of low strength, but highly oxidation-resistant, metal alloys to protect TD-NiCr at 2100° F (1149° C) from oxidation/erosion in a high velocity combustion gas environment. Five mil (0.127 mm) thick foils of Fe-25Cr-4Al-0.2Y; Fe-25Cr-0.2Y-0.5Ta; Fe-25Cr-4Al-1Y; and Ni-20Cr-5Al-0.5Th (nominal compositions) were isostatic hot pressure bonded to thoria dispersion strengthened nickel-chromium (Ni-20Cr-2.6w/o THO_2 commercially designated TD-NiCr). One hour exposures in the Mach 1 gas stream at 2100° F (1149° C) were followed by air blast quenching. The NiCrAl cladding offered complete protection for at least 120 hours and only showed signs of cladding failure in the maximum attack zone after 140 hours. All of the FeCrAlY claddings, however, failed within 20 to 40 hours in the maximum attack zone which is approximately the center of the hot zone. The best FeCrAlY cladding--the one with the most yttrium--lost from 1/3 to 1/2 of the cladding thickness, even in the average attack zone (approx. 2050° F or 1121° C) within 100 hours of testing. Metallographic examination showed considerable porosity and internal oxidation in all areas of the TD-NiCr substrate under sites of cladding failure. Furthermore, metallographic evidence of interdiffusion between NiCrAl and FeCrAlY claddings and TD-NiCr was observed to a depth of about 11 mils (0.3 mm) in TD-NiCr in 160 and 100 hours respectively at 2100° F (1149° C).

INTRODUCTION

Thoria dispersion strengthened nickel materials offer useful strengths at temperatures above the limits of many conventional cast nickel superalloys. For this reason, they are being considered for use in hot section components of advanced aircraft gas turbine engines. One such material, thoria dispersion strengthened nickel-20 chromium (TD-NiCr), has potential for stator vane use to approximately 2200° F (1204° C). Above about 1800° F (982° C), however, TD-NiCr rapidly loses weight in high velocity gas streams (ref. 1 and 2). Such losses are generally ascribed to the oxidation of Cr_2O_3, to volatile CrO_3, the normally observed surface oxide, and subsequent formation of less protective oxides, NiO and $NiCr_2O_4$, in the surface scale. For this reason, the exploitation of the strength of TD-NiCr in advanced high temperature engines requires improved oxidation resistance.

Ductile claddings offer one way to provide such surface protection (ref. 3). A number of weak but very oxidation resistant nickel-chromium-aluminum (NiCrAl) and iron-chromium-aluminum-yttrium (FeCrAlY) based alloys (ref. 4) were used for this purpose. These alloys form aluminum-rich scales and are very protective in furnace oxidation tests. The present study was directed towards the determination of the protective ability of such claddings in TD-NiCr. Here, tests were conducted in a high velocity burner rig at 2100° F (1149° C) for times to 160 hours in order to simulate an engine environment. The evaluation of cladding performance was based on visual examination, weight change, and metallographic analyses.

MATERIALS

Commercial nickel-20 w/o chromium 2.6 w/o thorium dioxide plate was machined into specimens 4 in. (101.6 mm) by 1 in. (25.4 mm) by 1/4 in. (6.3 mm) as shown in figure 1. These specimens were then clad with 5 mil (0.127 mm) foils by isostatic hot pressure bonding at 2000° F (1093° C) for 2 hours at 20,000 psi (138 MN/m^2). Four cladding materials (three produced in ref. 4 and a semi-commercial Fe-Cr-Al-Y alloy) were so applied. Their compositions were nominally Fe-25Cr-4Al-0.2Y; Fe-25Cr-4Al-0.2Y-0.5Ta; Fe-25Cr-4Al-1Y (General Electric Co. alloy 2541); and Ni-20Cr-5Al-0.5Th. Chemical analysis data for each cladding material are presented in table I.

TEST PROCEDURES

A Mach 1, natural gas fueled burner rig was used to test the clad specimens. Details of the rig and its operation can be found in reference 1. Since the air to fuel ratio was about 20:1, this facility simulates the oxidizing environment of an aircraft engine. Figure 2 contains a schematic diagram of this test facility. Eight specimens are placed in a rotating holder (450 rpm) directly in front of the exhaust nozzle. Once each hour the specimens are lowered out of the flame and subjected to air blast quenching (approx. 100° F/sec (55° C/sec) to 200° F (93° C)). All tests were conducted at a maximum metal temperature of 2100°±25° F (1149±15° C) for times to 160 hours. The maximum temperature occurred about 0.875 in. (2.2 cm) down from the specimen tip as shown in figure 1. Temperatures were initially monitored with a thermocoupled dummy specimen and were monitored throughout the test by corrected optical pyrometry.

After a number of 1 hour exposures, the specimens were allowed to cool to room temperature. They were removed from the holder and weighed. Some specimens were tested for only 20, 40, 60, or 100 hours depending on performance.

After test, the specimens were examined visually; sectioned through the zone of maximum attack and through a zone of average attack; (see fig. 1) and metallographically prepared and examined. Based on previous 2100° F (1149° C) tests in which temperature profiles were measured, the metal temperature in the zone of average attack was estimated to be about 2050° F (1121° C).

Results and Discussion

Visual appearance of the specimens of FeCrAl and NiCrAl clad TD-NiCr after various times at 2100° F (1149° C) are shown in figure 3. This figure shows that in the iron-base group, the low yttrium claddings are much more noticeably attacked than is the alloy with the highest yttrium. Also, while the Fe-25Cr-4Al-1Y specimen appeared to be the best of the FeCrAl alloys tested, it showed considerable attack after 100 hours while the NiCrAl cladding appeared in excellent condition after the same exposure. Only after 140 hours of testing at 2100° F (1149° C) did the NiCrAl begin to show failure at the leading and trailing edges.

These observations are supported by the weight change data presented in figure 4. The FeCrAlY alloy containing tantalum lost the most weight and lost it more rapidly than any of the other alloys tested. Indeed, after about 40 hours it lost weight more rapidly than did the unprotected TD-NiCr. While the claddings without tantalum were better, the low yttrium claddings lost about twice as much weight as the best FeCrAlY cladding--the one with the highest yttrium--which lost 1117 mgs in 100 hours. None of these claddings exhibited performance even approaching that of the NiCrAl clad TD-NiCr. After 100 hours the NiCrAl showed a total loss of only 90 mgs. Based on an average hot zone area of 30 cm^2, this is a loss of only 3 mg/cm^2 and indicates a very protective system. Even after 160 hours, this system only lost 622 mgs or about 21 mg/cm^2.

The potential of the better cladding systems for vane service at these temperatures can be seen in figure 4. The claddings do not lose weight nearly as rapidly or as soon as WI-52 (ref. 5) coated with the commercial aluminide coating that is used to protect WI-52 vanes in many current, commercial aircraft gas turbine engines.

The results of the metallographic analyses on the zones of maximum and average attack--both at the leading edge of the specimen and along the taper slightly back from the leading edge--are presented in figures 5 and 6. Figure 5 presents the metallography for the Fe-25Cr-4Al-1Y cladding--the best of the FeCrAlY alloys tested. In the maximum attack zone, the cladding was completely lost at the leading edge after the 100 hour exposure at 2100° F (1149° C). This region also shows considerable internal oxidation and the presence of many large voids. Along the taper in the maximum attack zone the useful remaining cladding thickness varied from around 2 to 3 mils (0.05 to 0.08 mm). This represents a loss of about 1/2 to 1/3 of the original cladding thickness. Even in the average attack zone, a small amount of cladding remains at the leading edge but this is difficult to observe in the etched photomicrograph (fig. 5). However, around 3 mils (0.08 mm) remains at the taper. These data indicate severe oxidation and loss of cladding in this system under the test conditions employed. While not illustrated in this report, metallographic changes were observed in the TD-NiCr substrate to a depth of about 11 mils (0.3 mm) beneath the cladding. Some interdiffusion of cladding constituents must have occurred in this region. This may have been accompanied by the outward diffusion of nickel into the cladding. Such diffusion has potential to degrade the protective ability of the FeCrAl claddings. These preliminary findings indicate that diffusion barriers may be required to improve the performance of such systems. A contractual effort is currently examining this possibility (information from A. R. Stetson of the Solar Division of International Harvester under NASA Contract NAS 3-14312).

Figure 6 shows a similar series of photographs for the NiCrAl cladding after 160 hours of testing. This is 60 percent more time at temperature than for the FeCrAl cladding micrographs shown in figure 5. Here, too, however, the leading edge shows complete loss of cladding in the maximum attack zone. This loss was also accompanied by voids and internal oxidation. However, along the taper, the cladding was only degraded very near the leading edge away from it the cladding was nearly its original thickness. In the zone of average attack, which corresponds to a metal temperature of only about 50° F (28° C) lower than that of the zone of maximum attack, the cladding only suffered minor surface oxidation. While some differences in the TD-NiCr were also visible here to a depth of about 11 mils (0.3 mm), the attendant interdiffusion must not have been as harmful to the oxidation resistance of the cladding as was the case in the FeCrAl systems. However, if aluminum is lost from the cladding to the TD-NiCr, protection life might be improved if suitable diffusion barriers could be developed for this system as well.

CONCLUSIONS

Several FeCrAl and NiCrAl cladding alloys in the form of 5 mil (0.127 mm) thick foils were diffusion bonded to TD-NiCr specimens and tested in a Mach 1 burner rig for times to 160 hours. The maximum test temperature was 2100° F (1149° C). Visual examination, weight change, and metallographic analyses were used to evaluate the protective ability of each cladding. The results of this effort lead to the following conclusions.

1. The NiCrAl cladding appears more protective than any of the FeCrAlY types examined. It survived at least 120 hours at 2100° F (1149° C) while the best FeCrAlY cladding showed signs of failure well before 100 hours of testing.

2. The FeCrAlY claddings appear to be significantly degraded by oxidation in this test facility (perhaps traceable to interdiffusion with TD-NiCr) within 20 to 40 hours. Even in the average attack region, the best of these claddings lost 1/3 to 1/2 of the original cladding thickness in 100 hours of testing.

3. The NiCrAl cladding appeared to have suffered only minor surface oxidation in 160 hours in a region in which the test temperature was estimated to be about 2050° F (1121° C).

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TABLE I - CHEMICAL ANALYSIS

Nominal composition, weight percent	Analyzed Composition, weight percent						
	Fe	Cr	Al	Y	Ta	Th	Ni
Fe-25Cr-4Al-0.2Y	Bal	24.43	4.06	0.27	----	----	---
Fe-25Cr-4Al-02Y-0.5Ta	Bal	24.82	4.16	.08	0.54	----	---
Fe-25Cr-4Al-1.0Y	Bal	25.04	4.10	.58	----	----	---
Ni-20Cr-5Al-0.5Th	---	20.04	4.88	----	----	0.44	Bal

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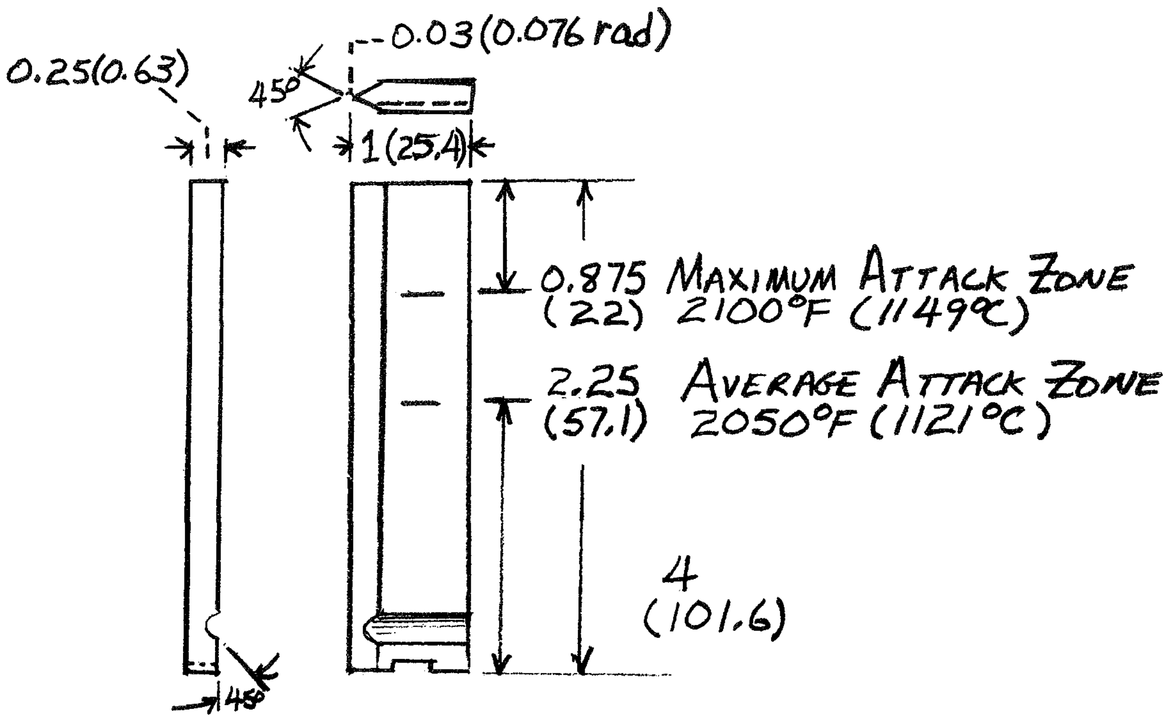

Figure 1. High-Velocity Oxidation Specimen

(Dimensions are in inches(mm))

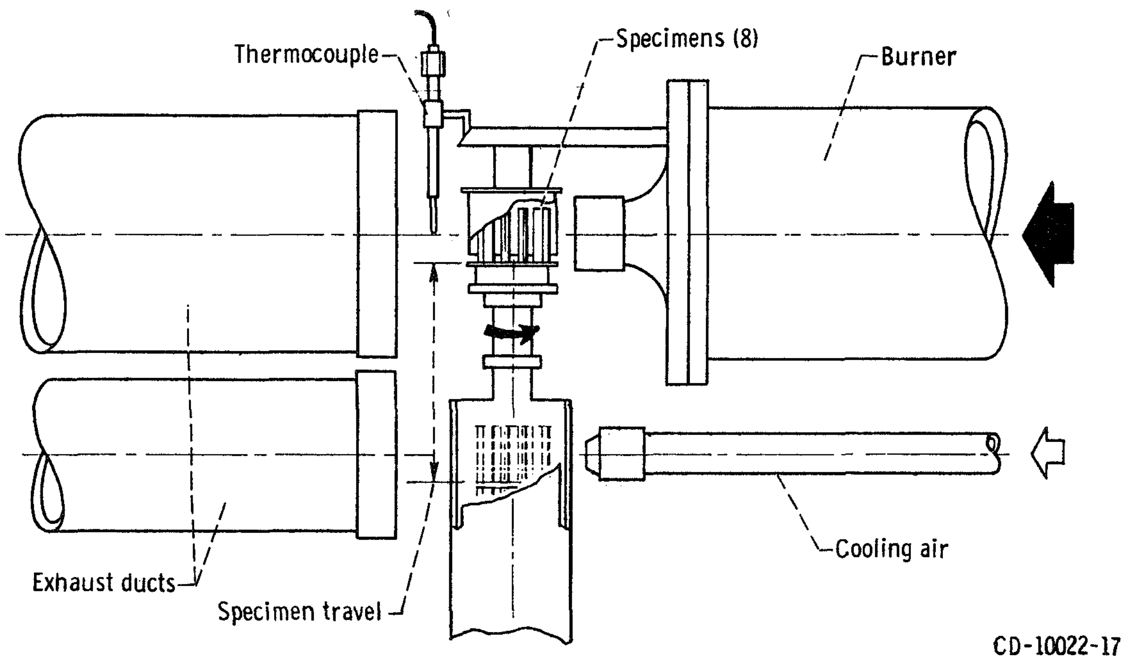

Figure 2. - Schematic of burner rig.

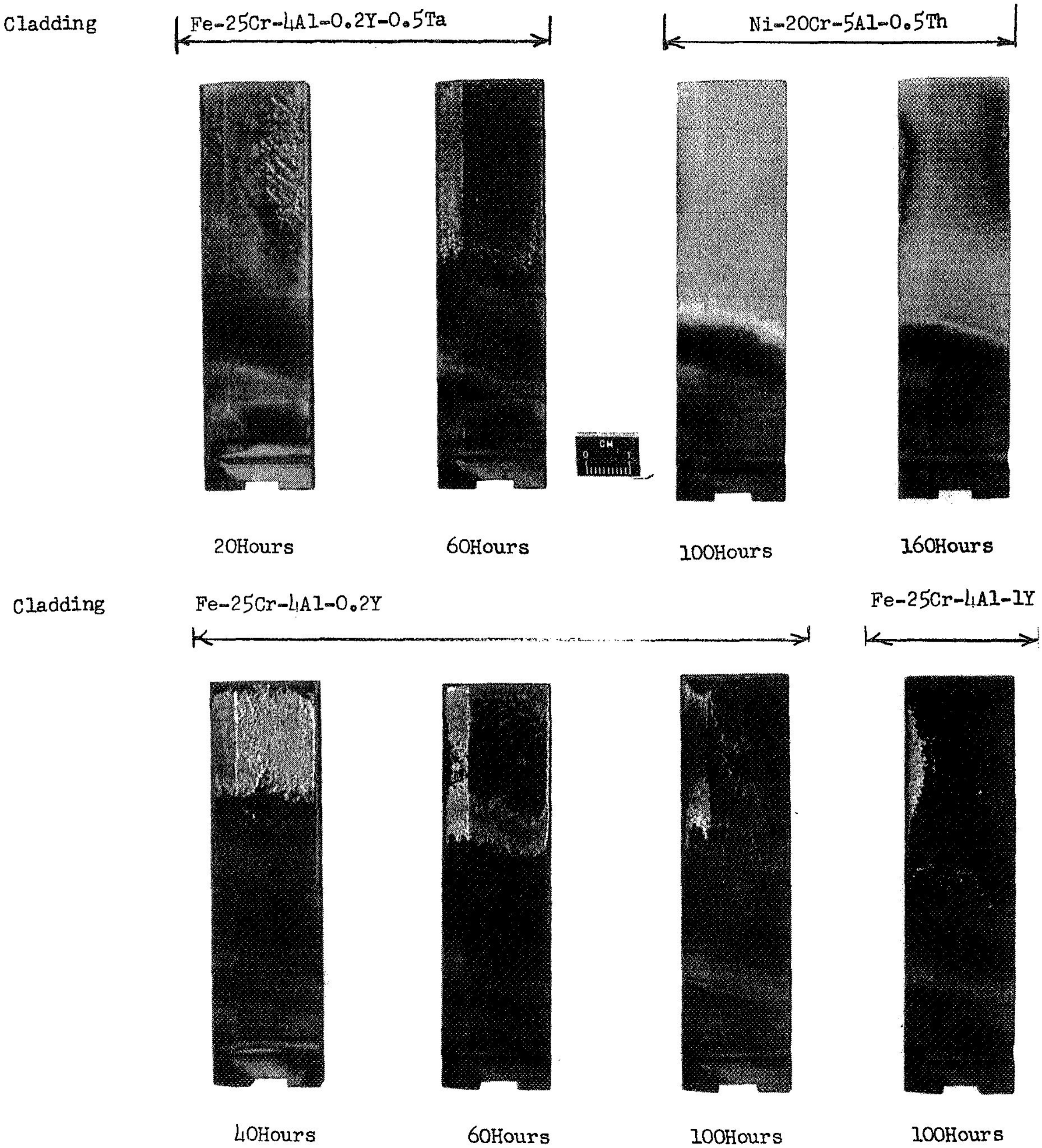

Figure 3. Visual Appearance of 5 mil(0.127mm) Clad Specimens of TD-NiCr after Various Times at 2100°F (1149°C)

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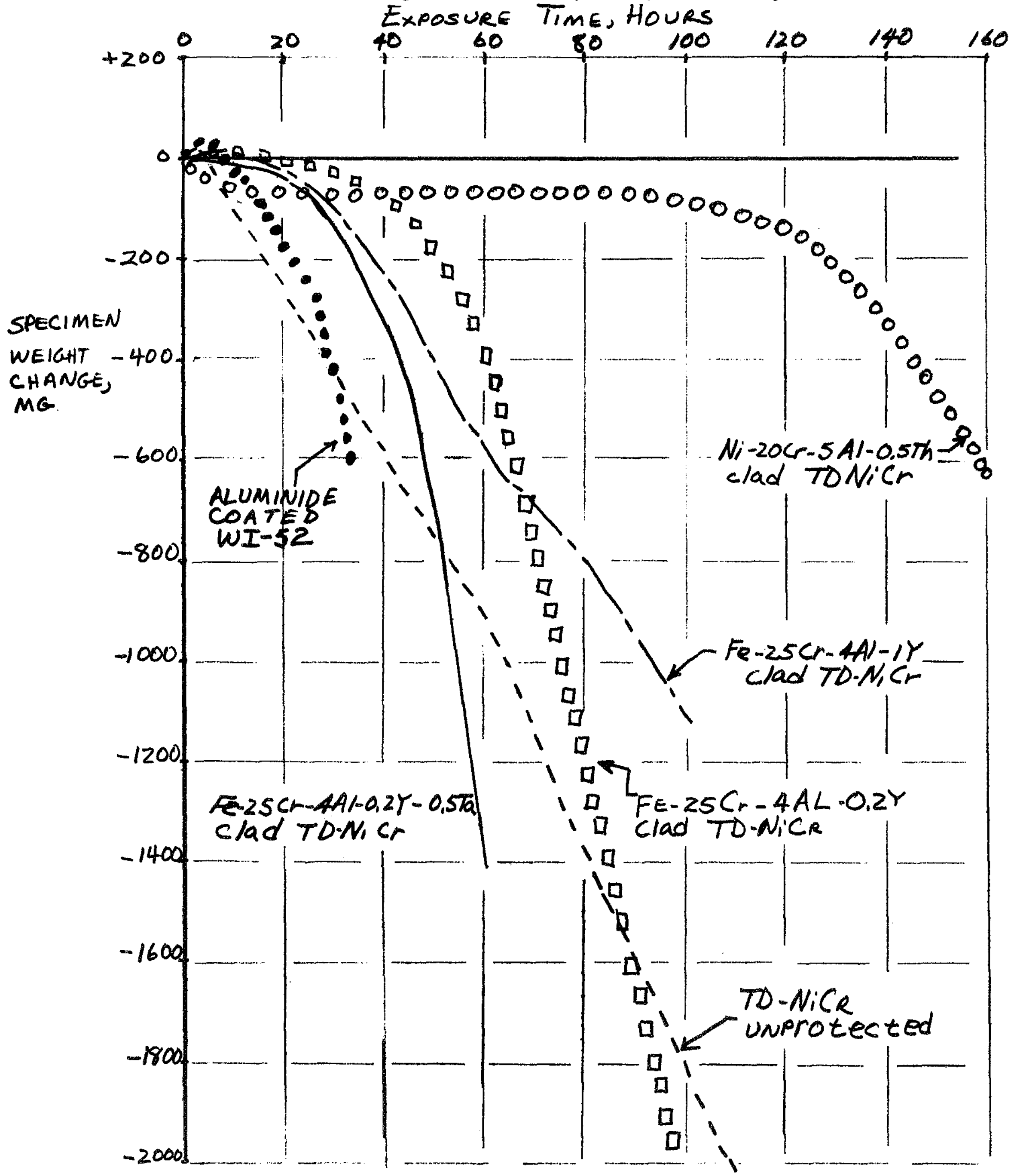
Figure 4. Cyclic Oxidation Resistance of Alloy Foil Clad (5 mils or 0.127mm) and Unprotected TD-NiCr:

Mach 1 Burner Rig Tests - 2100°F(1149°C) - 1 Hour Cycles



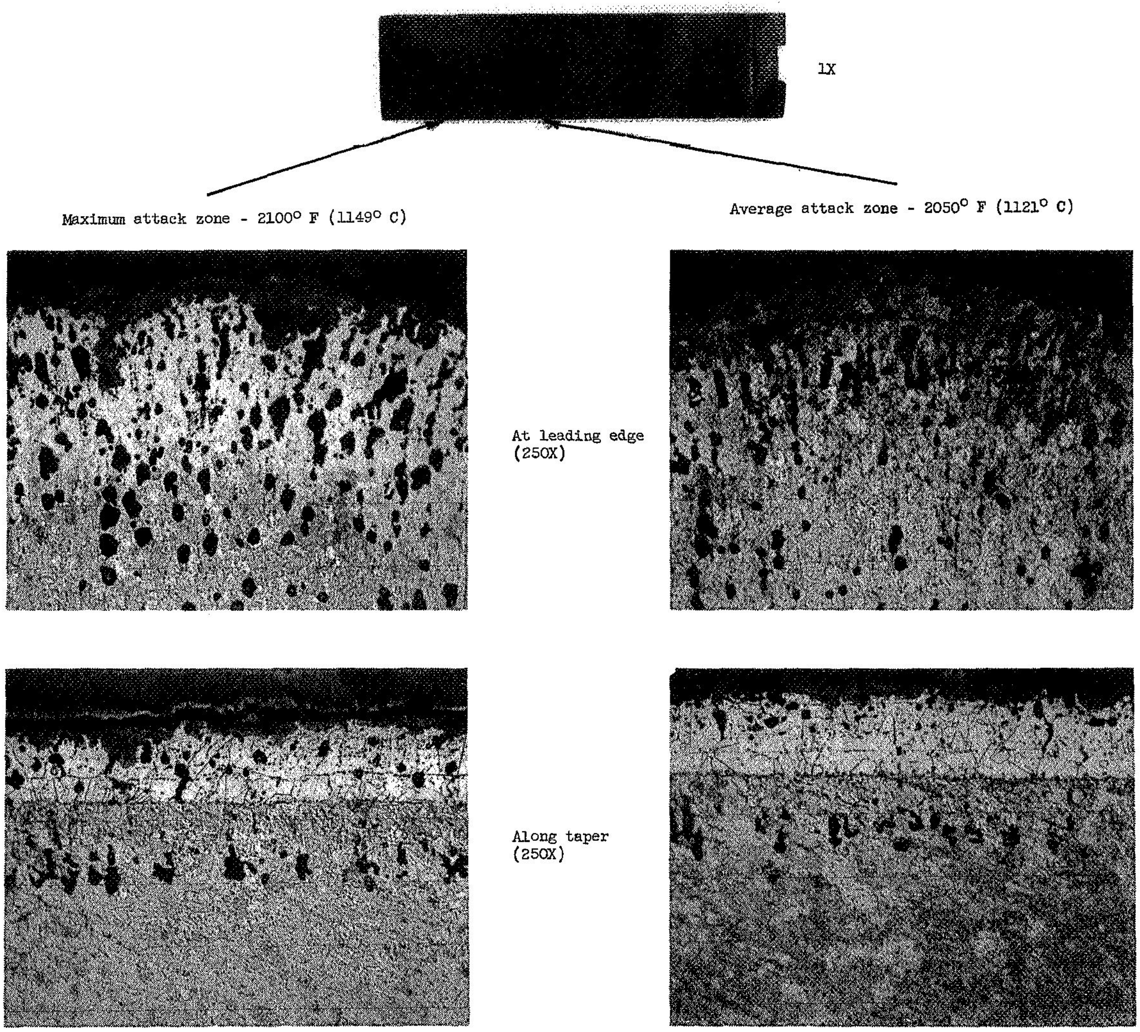


Figure 5. - Fe-25Cr-4Al-1Y clad TD-NiCr (Burner rig tested: 2100° F - 100 hours-Mach 1).

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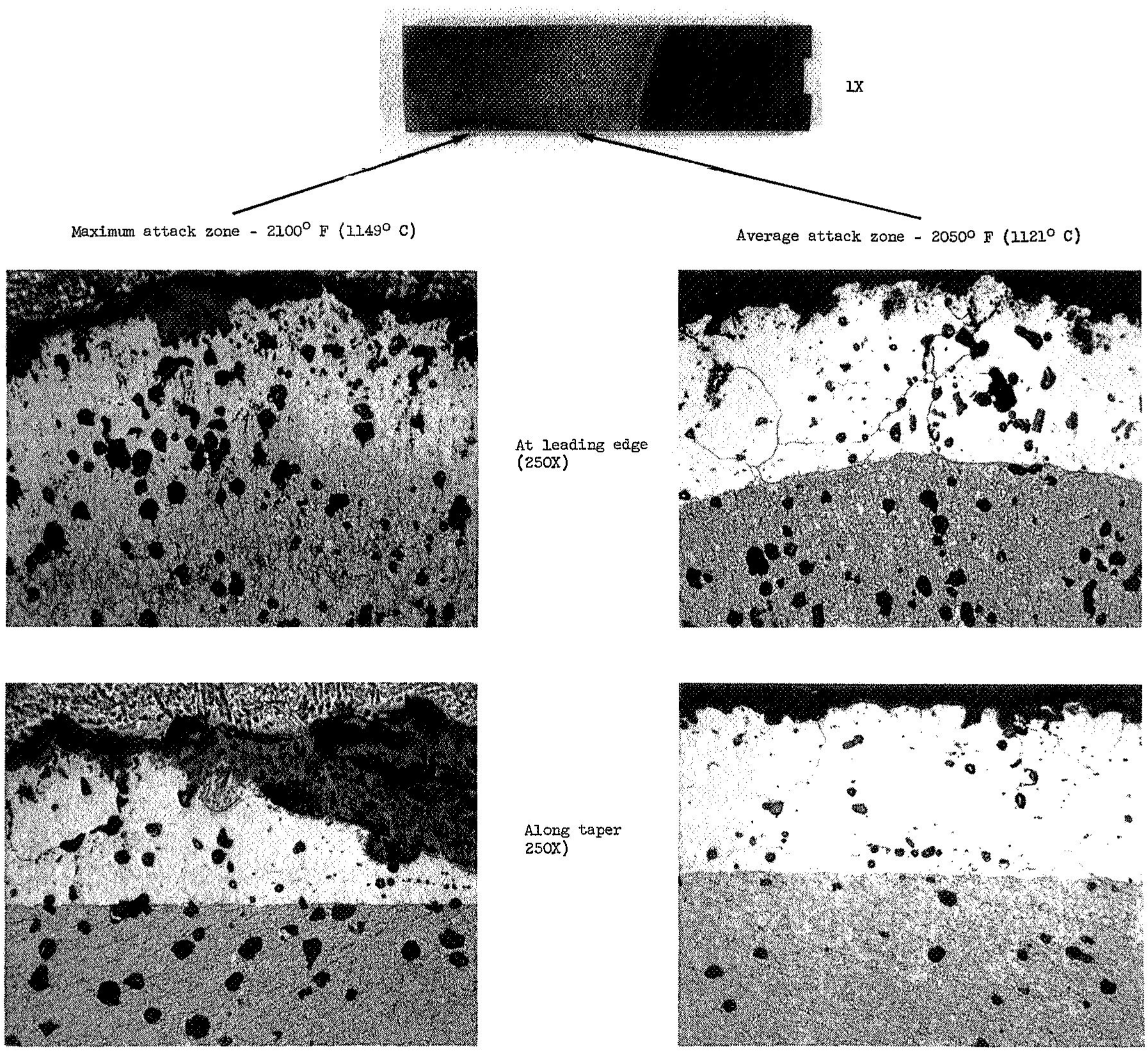

Figure 6. - Ni-20Cr-5Al-0.5Th Clad TD-NiCr (Burner rig tested: 2100° F-160 hours-Mach 1).