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THE EFFECTS OF A RANGE OF MACHINED AND GROUND SURFACE FINISHES ON THE SIMULATED REACTOR HELIUM CORROSION OF SEVERAL CANDIDATE STRUCTURAL MATERIALS

by
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ABSTRACT

This report discusses the corrosion behavior of several candidate reactor structural alloys in a simulated advanced high-temperature gas-cooled reactor (HTGR) environment over a range of, lathe-machined and centerless-ground surface finishes. The program used a controlled-impurity helium environment of 50 Pa H₂/5 Pa CO/5 Pa CH₄/ <0.05 Pa H₂O (500 μ atm H₂/50 μ atm CO/50 μ atm CH₄/ <0.5 μ atm H₂O) at 900°C for a total exposure of 3000 h. The test alloys included two vacuum-cast superalloys (IN 100 and IN 713LC); a centrifugally cast austenitic alloy (HK 40); three wrought high-temperature alloys (Alloy 800H, Hastelloy X, and Inconel 617); and a nickel-base oxide-dispersion-strengthened alloy (Inconel MA 754).

In these experiments, surface finish variations did not affect the simulated advanced-HTGR corrosion behavior of these materials. Under these conditions, the availability of reactant gaseous impurities controls the kinetics of the observed gas-metal interactions. Variations in the near-surface activities and mobilities of reactive solute elements, such as chromium, which might be expected to be affected by changes in surface finish, do not seem to greatly influence corrosion in this simulated advanced HTGR environment.

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1. INTRODUCTION

The purpose of this program was to investigate the effects of various laboratory and commercial surface finishes on the controlled-impurity helium corrosion behavior of seven candidate metallic structural materials for an advanced high-temperature gas-cooled reactor (HTGR). The test alloys included three wrought high-temperature alloys (Alloy 800H, Hastelloy X, and Inconel 617); two vacuum-cast superalloys (IN 100 and IN 713LC); one centrifugally cast high-temperature austenitic alloy (HK 40); and a nickel-base oxide-dispersion-strengthened alloy (Inconel MA 754).

The program studied lapped, pickled, grit-blasted, preoxidized, lathe-machined, and centerless-ground surface finishes. Run 1 comprised alloy specimens with lapped, pickled, grit-blasted and preoxidized surface conditions. Earlier papers (Refs. 1 and 2) reported these results. This report discusses the Run 2 results, comprising control specimens and specimens with various lathe-machined and centerless-ground finishes.

2. EXPERIMENTAL PROCEDURES

Table 1 shows the test matrix adopted to study surface finish condition effects in a simulated advanced HTGR environment. This matrix includes typical industrial practices, such as pickling, grit-blasting, and machining; finish preparation techniques that are more laboratory related (e.g., lapping); and preoxidation treatments in air, which form oxide surface scales and can be viewed as a simplistic coating application procedure. Earlier papers (Refs. 1 and 2) documented the Run 1 results. This report presents the results of Phase I, Run 2 exposures.

2.1. TEST SPECIMENS

Test alloys included promising alloy systems from various categories of presently available commercial materials that may find application in advanced HTGRs: two vacuum-cast superalloys (IN 100 and IN 713LC); one centrifugally cast high-temperature austenitic alloy (HK 40); three wrought high-temperature alloys (Alloy 800H, Inconel 617, and Hastelloy X); and a nickel-base oxide-dispersion-strengthened material (Inconel MA 754). Table 2 gives the chemical compositions, heat numbers, and as-received conditions of the materials tested. In the case of HK 40, specimens were machined from a remnant piece of cast tube, and the heat number could not be determined; therefore, Table 2 gives the General Atomic (GA) heat code number instead.

An earlier report (Ref. 1) more completely described the materials used in this investigation. No unusual or disturbing microstructural features were noted on the heats of materials studied.

TABLE 1
REVISED GENERAL ATOMIC TEST MATRIX, EFFECTS OF SURFACE CONDITION ON THE
CORROSION OF STRUCTURAL MATERIALS IN ADVANCED-HTGR HELIUM

	Vacuum Shell Cast Alloys		Centrifugally Cast Alloy HK 40	Wrought Alloys			Y ₂ O ₃ Dispersed MA 754
	RENE 100	IN 713		Alloy 800H	Hast. X	Inc. 617	
Phase I - Run 1 (900°C, 3000 h.)							
Preoxidized, 900°C, in air							
100 h	X	X	X	X	X	X	X
10 h	X	X	X	X	X	X	X
1 h	X	X	X	X	X	X	X
Lapped, 0.254-0.127 μm (10-5 μin.)	X	X	X	X	X	X	X
Grit-blasted	X	X	X	X	X	X	
Pickled				X	X	X	X
KFA ^(a) specimens	Standard finish						
Phase I - Run 2 (900°C, 3000 h)							
Machined, 3.18 - 0.81 μm (125-32 μin.)							
3.18 μm (125 μin.)			X	X	X	X	X
1.63 μm (64 μin.)			X	X	X	X	X
0.81 μm (32 μin.)			X	X	X	X	X
Ground, 1.63-0.10 μm (64-4 μin.)							
1.63 μm (64 μin.)	X	X	X	X	X	X	X
0.81 μm (32 μin.)	X	X	X	X	X	X	X
0.10 μm (4 μin.)	X	X	X	X	X	X	X
Phase II - A detailed evaluation of scale formation kinetics/characteristics with selected alloys/ conditions and initiation of similar studies involving other environments, temperatures, and additional pertinent surface conditions.							

(a) Institute für Reaktorwerkstoffe der Kernforschungsanlage.

TABLE 2
CHEMICAL COMPOSITION OF TEST ALLOY SYSTEMS (VENDOR VALUES)

Alloy (Heat) As-Received Condition	Composition (wt %)																			
	C	Ni	Fe	Cr	Mn	Si	Mo	Co	W	Nb	Ta	Al	Ti	Cu	V	Zr	B	P	S	Y ₂ O ₃
Hastelloy X (126007437) Solution- annealed	0.07	Bal.	18.97	22.06	0.61	0.44	8.79	1.69	0.67	--	--	--	--	--	--	--	0.002	0.02	<0.002	--
Inconel 617 (XX14A6UK) Solution- annealed	0.06	55.13	0.53	21.74	0.02	0.10	8.91	12.32	--	--	--	1.11	0.30	0.11	--	--	0.003	--	0.002	--
Alloy 800H (HH8099A) Solution- annealed	0.07	32.03	45.50	19.79	1.00	0.18	--	--	--	--	--	0.38	0.45	0.60	--	--	--	--	0.003	--
HK 40 (GA321)(a) As centrif- gally cast	0.41	20.1	Bal.	25.3	0.39	1.23	--	--	--	--	--	--	--	--	--	--	--	--	--	--
IN 100 (UA0457111047) As-cast	0.18	Bal.	0.20	9.85	<0.10	<0.10	3.03	15.18	--	--	--	5.46	4.19	--	1.05	0.07	0.015	--	0.0016	--
IN 713LC (WA39866B6965) As-cast	0.06	Bal.	0.15	12.00	<0.10	<0.10	4.10	0.10	--	--	2.04 (Nb+Ta)	5.85	0.71	<0.10	--	0.06	0.007	0.002	0.0015	--
Inconel MA 754 (DT02A8B1-2) Mechanically alloyed	0.07	76.11	1.52	20.68	--	--	--	--	--	--	--	0.30	0.40	--	--	--	--	--	0.003	0.58

(a) General Atomic code number.

2.2. SURFACE PREPARATION

The specimens to be exposed in the simulated advanced HTGR environment were carefully prepared to give surfaces typical of the following treatments: (1) lathe-machining and (2) centerless grinding. Run 2 also included control specimens with a centerless-ground $0.4\text{ }\mu\text{m}$ ($16\text{ }\mu\text{in.}$) surface finish, a typical finish on all previously studied specimens (Refs. 3 through 6).

All corrosion test specimens were in the form of 6.35-mm (0.25-in.) diameter by 25.4-mm (1.00-in.) long cylinders with a centrally located 3.17-mm (0.125-in.) diameter hole drilled near one end for positioning in the specimen holder.

Specimens of the cast superalloys (IN 100 and IN 713LC) were sliced from 6.35-mm (0.25-in.) diameter by 76.2-mm (3.00-in.) long as-cast bars. These specimens were grit-blasted at the foundry with 90 to 120 mesh alumina, typical of cast turbine components. These two alloys were surface-prepared with the specimens in the grit-blasted initial condition.

The wrought, oxide-dispersion-strengthened, and centrifugally cast alloy specimens were machined from bar stock, flat stock, and longitudinally cut blanks, respectively, resulting in a uniform surface finish of 0.2 to $0.4\text{ }\mu\text{m}$ (8 to $16\text{ }\mu\text{in.}$). Any surface preparation for these alloys was performed with the specimen in this initial condition.

This program studied a range of lathe-machined and centerless-ground surface conditions for the wrought alloys HK 40 and Inconel MA 754. Only centerless-ground surface conditions were considered for the cast superalloy, since machining these materials is not practical. Table 3 shows the actual test specimen surface conditions. A surface profilometer was used to determine the specific surface condition on all specimens following preparation.

TABLE 3
ACTUAL LATHE-MACHINED AND
CENTERLESS-GROUND SURFACE CONDITIONS STUDIED

Alloy	Lathe-Machine Finishes [μm ($\mu\text{in.}$)]	Centerless-Ground Finishes [μm ($\mu\text{in.}$)].
Alloy 800H	0.81 (32) 1.57 (62) 3.68 (145)	0.20 (8) 0.86 (34) 1.63 (64)
Hastelloy X	0.84 (33) 1.85 (73) 3.94 (155)	0.10 (4) 0.91 (36) 1.14 (45)
Inconel 617	1.63 (64) 3.05 (120)	0.20 (8) 0.66 (26) 0.91 (36)
IN 100	N/A	0.18 (7) 0.76 (30) 0.77 (30)
IN 713LC	N/A	0.13 (5) 0.61 (24) 0.62 (24)
HK 40	0.81 (32) 1.27 (50) 2.79 (110)	0.10 (4) 0.81 (32) 0.91 (36)
Inconel MA 754	0.97 (38) 1.24 (49) 3.18 (125)	0.15 (6) 1.02 (40) 1.04 (41)

Figures 1 and 2 show sample test specimen surface finishes. A specific surface condition had little alloy-to-alloy variation.

2.3. CONTROLLED-IMPURITY HELIUM EXPOSURE (Ref. 3)

The specimens were exposed isothermally at 900°C (1625°F) for 3000 h, with interruptions at 500, 1000, 2000, and 3000 h for weight change measurements. Exposures were conducted in a simulated advanced HTGR environment, consisting of helium containing constant concentrations of 50 Pa H₂/5 Pa CO/5 Pa CH₄/ <0.05 Pa H₂O (500 μ atm H₂/50 μ atm CO/50 μ atm CH₄/ <0.5 μ atm H₂O).

Figure 3 (Ref. 3) shows a schematic diagram of the once-through controlled-impurity helium supply system used to generate each desired helium environment. Bottled high-purity nuclear-grade helium was further purified by passing it through a 5 Å molecular sieve and activated charcoal trap at liquid nitrogen temperature [196°C (-321°F)]. Controlled quantities of H₂, CO, and CH₄ were added by metering research-purity gases into the purified helium stream. Each controlled-impurity helium mixture was then introduced into a high-temperature retort and exhausted to the atmosphere. In the present experiments, H₂O was not intentionally added.

An important consideration in the test system design was to minimize impurity depletion in the retorts so that gas of known and constant composition would be available to react with all specimens during exposure. Specimens were contained in alumina sample holders and exposed in 70-mm (2.75-in.) i.d. by 910-mm (36-in.) long, single-ended alumina retorts, using an alumina gas inlet tube to eliminate reactive metal surfaces other than the specimens themselves. In addition to these precautions, flow rates through each retort were maintained at 1000 cm³/min to further minimize changes in gas composition from inlet to outlet. The impure helium gas mixtures in the retorts were maintained at positive (0.167 MPa) pressure to minimize possible air leaks into the test system. Heating of the retorts was accomplished using three-zone Lindberg horizontal tube furnaces with a 610-mm

(a)

(b)

(c)

Fig. 1. Scanning electron micrographs showing typical lathe-machined surface finishes of Inconel MA 754 test specimens: (a) $0.965\text{ }\mu\text{m}$ ($38\text{ }\mu\text{in.}$), (b) $1.245\text{ }\mu\text{m}$ ($49\text{ }\mu\text{in.}$), and (c) $3.175\text{ }\mu\text{m}$ ($125\text{ }\mu\text{in.}$) finishes

(a)

(b)

(c)

Fig. 2. Scanning electron micrographs showing typical centerless-ground surface finishes of alloy 800H test specimens: (a) $0.203\text{ }\mu\text{m}$ (8 $\mu\text{in.}$), (b) $0.864\text{ }\mu\text{m}$ (34 $\mu\text{in.}$), and (c) $1.626\text{ }\mu\text{m}$ (64 $\mu\text{in.}$) finishes

Fig. 3. Schematic diagram of environmental control system for parametric helium impurity corrosion study (Ref. 3)

(24-in.) hot zone. The 75-mm (3-in.) long test zone contained three equally spaced monitoring thermocouples along its length. The center thermocouple controlled the furnace. Test zone temperature was maintained to within $\pm 5^{\circ}\text{C}$ ($\pm 9^{\circ}\text{F}$).

Test monitoring instrumentation included a Carle Model III H (S series) automatic gas chromatograph to determine H_2 , CO , CO_2 , and CH_4 partial pressures; an EG&G Model 440 extended-range dew point hydrometer to determine H_2O partial pressure; and a modified Thermox zirconia cell oxygen probe to qualitatively determine O_2 partial pressure. The helium composition in and out of each retort was measured at least once weekly, and H_2 , CO , and CH_4 levels were maintained to within $\pm 10\%$ of nominal.

2.4. TEST PROCEDURE

Exposure of the specimens was interrupted at 100, 500, 1000, 2000, and 3000 h for visual examination and weight change measurements. Specimens were removed after 3000-h exposures for destructive analyses. All corrosion specimens removed from testing were cut perpendicular to their longitudinal axis to obtain sections for metallography, bulk carbon analysis, and surface studies.

Metallography of etched and unetched sections was employed to study surface corrosion scales, internal oxidation, carburization, and thermal aging effects. Mean oxidation and carburization depths were measured by averaging eight metallographic measurements around the specimen cross section.

3. EXPERIMENTAL RESULTS

Figure 4 shows the weight change data as a function of exposure time for the seven candidate materials. Figures 4a through 4c indicate similar wrought alloy behavior, regardless of surface condition. Slight variations between specimens are not believed to be significant. Figures 4d and 4e show similar change in specimen weight for cast superalloys for each centerless-ground condition. Again, no major significance is attributed to variations between the centerless-ground and the control specimens.

Figure 4f clearly demonstrates the effects of surface scale spallation on the HK 40 weight change curves. Previous controlled-impurity helium studies (Refs. 1 through 6) showed HK 40 surface scale spallation. These studies recorded sharp decreases in specimen weight. The lathe-machined specimens were more susceptible to surface scale spallation than the centerless-ground specimens (except the control specimens, which was also ground). Figure 4g shows a short-term weight loss, attributed to decarburization (Refs. 5 and 6), combined with a tendency to gain weight as the exposure time increased for Inconel MA 754. This latter change was consistent with the formation of a surface oxide scale, which thickened slightly with increased exposure time. The large decrease for the 1.24- μm (49- $\mu\text{in.}$) machined specimen could represent an initial weight error, since the specimen behaved consistently with the other specimens after the first test interruption (100 h).

Optical metallography techniques were employed on the specimen cross-sections to determine if the range of surface finishes discernably affected surface scale formation. Figures 5 through 11 show the typical specimen surface scales and corresponding differential-interference-contrast (DIC) micrographs. The measured carburization depths are taken as the near-surface depth of enhanced carbide precipitation. In all cases, surface

Fig. 4. Weight change data for test alloys following exposure for 3000 h at 900°C to controlled-impurity helium containing 50 Pa H₂/5 Pa CO/5 Pa CH₄/ <0.05 Pa H₂O (500 μ atm H₂/50 μ atm CO/50 μ atm CH₄/ <0.5 atm H₂O): (a) Alloy 800 H (sheet 1 of 7)

Fig. 4. Weight change data for test alloys following exposure for 3000 h at 900°C to controlled-impurity helium containing 50 Pa H₂/5 Pa CO/5 Pa CH₄/ <0.05 Pa H₂O (500 μ atm H₂/50 μ atm CO/50 μ atm CH₄/ <0.5 atm H₂O): (b) Hastelloy X (sheet 2 of 7)

Fig. 4. Weight change data for test alloys following exposure for 3000 h at 900°C to controlled-impurity helium containing 50 Pa H₂/5 Pa CO/5 Pa CH₄/ <0.05 Pa H₂O (500 μatm H₂/50 μatm CO/50 μatm CH₄/ <0.5 atm H₂O): (c) Inconel 617 (sheet 3 of 7)

Fig. 4. Weight change data for test alloys following exposure for 3000 h at 900°C to controlled-impurity helium containing 50 Pa H₂/5 Pa CO/5 Pa CH₄/ <0.05 Pa H₂O. (500 μ atm H₂/50 μ atm CO/50 μ atm CH₄/ <0.5 atm H₂O): (d) IN 100 (sheet 4 of 7)

Fig. 4. Weight change data for test alloys following exposure for 3000 h at 900°C to controlled-impurity helium containing 50 Pa H₂/5 Pa CO/5 Pa CH₄/ <0.05 Pa H₂O (500 μatm H₂/50 μatm CO/50 μatm CH₄/ <0.5 atm H₂O): (e) IN 713LC (sheet 5 of 7)

Fig. 4. Weight change data for test alloys following exposure for 3000 h at 900°C to controlled-impurity helium containing 50 Pa H₂/5 Pa CO/5 Pa CH₄/ <0.05 Pa H₂O (500 μatm H₂/50 μatm CO/50 μatm CH₄/ <0.5 atm H₂O): (f) HK 40 (sheet 6 of 7)

Fig. 4. Weight change data for test alloys following exposure for 3000 h at 900°C to controlled-impurity helium containing 50 Pa H₂/5 Pa CO/5 Pa CH₄/ <0.05 H₂O (500 μ atm H₂/50 μ atm CO/50 μ atm CH₄/ <0.5 atm H₂O): (g) MA 754 (sheet 7 of 7)

Fig. 5. Optical micrographs showing the typical surface scale formed on the control and on all of the lathe-machined and centerless-ground Alloy 800H specimens following a controlled-impurity helium exposure at 900°C for 3000 h: (a) lathe-machined specimen with a finish of 0.813 μm (32 $\mu\text{in.}$), (b) control specimen, and (c) differential-interference-contrast photograph

(a)

(b)

Fig. 6. Optical micrographs showing the typical surface scale formed on the control and on all of the lathe-machined and centerless-ground Hastelloy X specimens following a controlled-impurity helium exposure at 900°C for 3000 h: (a) centerless-ground specimen with a finish of 1.143 μm (45 $\mu\text{in.}$) and (b) differential-interference-contrast photograph

(a)

(b)

Fig. 7. Optical micrographs showing the typical surface scale formed on the control and on all of the lathe-machined and centerless-ground Inconel 617 specimens following a controlled-impurity helium exposure at 900°C for 3000 h: (a) lathe-machined specimen with a finish of 3.048 μm (120 $\mu\text{in.}$) and (b) differential-interference-contrast photograph

(a)

(b)

Fig. 8. Optical micrographs showing the typical surface scale formed on the control and on all of the centerless-ground IN 100 specimens following a controlled-impurity helium exposure at 900°C for 3000 h: (a) centerless-ground specimen with a finish of 0.178 μm (7 $\mu\text{in.}$) and (b) differential-interference-contrast photograph

(a)

(b)

Fig. 9. Optical micrographs showing the typical surface scale formed on the control and on all of the centerless-ground IN 713LC specimens following a controlled-impurity helium exposure at 900°C for 3000 h: (a) centerless-ground specimen with a finish of 0.61 μm (24 μin.) and (b) differential-interference-contrast photograph

(a)

(b)

Fig. 10. Optical micrographs showing the typical surface scale formed on the control and on all of the lathe-machined and centerless-ground HK 40 specimens following a controlled-impurity helium exposure at 900°C for 3000 h: (a) centerless-ground specimen with a finish of 0.813 μm (32 μin.) and (b) differential-interference-contrast photograph

(a)

(b)

Fig. 11. Optical micrographs showing the typical surface scale formed on the control and on all of the lathe-machined and centerless-ground Inconel MA 754 specimens following a controlled-impurity helium exposure at 900°C for 3000 h: (a) lathe-machined specimen with a finish of 1.245 μm (49 $\mu\text{in.}$) and (b) differential-interference-contrast photograph. Note: No carburization.

scale characteristics show no readily apparent differences after a 3000-h exposure. The surface scale types were consistent with those observed for the respective materials in earlier studies (Refs. 3 through 6).

Bulk carbon analyses of (corrosion specimen) cross sections quantitatively indicated the degree of carburization. Figures 12 through 18 show the results of these measurements; the wrought alloy specimens carburized significantly in 3000 h of simulated advanced-HTGR helium exposure. The specific increase in carbon concentration did not seem to vary consistently with surface finish.

The increase in carbon concentration for all cast superalloy test specimens was quite uniform, as shown in Figs. 15 and 16.

As Fig. 17 shows, HK 40 specimens carburized less than the previous alloys. Again, values were quite uniform and independent of initial surface condition. The HK 40 specimens are believed to increase in carbon concentration relatively less because the alloy has a high initial carbon concentration (0.41%), thereby decreasing the carburization driving force (Refs. 3 through 6) in this environment. This alloy also formed a thin silica (SiO_2) scale beneath external, often spalling, chromium-rich oxide scales. Other studies (Refs. 3 through 6) speculated that this SiO_2 scale inhibits carburization.

Figure 18 shows the Inconel MA 754 test specimen data. Ordinarily, Inconel MA 754 specimens have been observed to decarburize under a wide variety of simulated reactor environmental conditions (Refs. 3 through 6). Only in a few cases has this alloy been observed to carburize (Ref. 7). All the lathe-machined specimens decarburized, while the control and the centerless-ground specimens were slightly carburized. All specimen surface scales were similar. This carburization of the latter specimens, although not very severe, is not presently understood.

Fig. 12. Bulk carbon concentrations for alloy 800H specimens following exposure for 3000 h at 900°C to controlled-impurity helium containing 50 Pa H₂/5 Pa CO/5 Pa CH₄/ <0.05 Pa H₂O (500 μatm H₂/50 μatm CO/50 μatm CH₄/ <0.5 μatm H₂O).

Fig. 13. Bulk carbon concentrations for Hastelloy X specimens following exposure for 3000 h at 900°C to controlled-impurity helium containing 50 Pa H₂/5 Pa CO/5 Pa CH₄/ <0.05 Pa H₂O (500 μatm H₂/50 μatm CO/50 μatm CH₄/ <0.5 μatm H₂O)

Fig. 14. Bulk carbon concentrations for Inconel 617 specimens following exposure for 3000 h at 900°C to controlled-impurity helium containing 50 Pa H₂/5 Pa CO/5 Pa CH₄/ <0.05 Pa H₂O (500 μatm H₂/50 μatm CO/50 μatm CH₄/ <0.5 μatm H₂O)

Fig. 15. Bulk carbon concentrations for IN 100 specimens following exposure for 3000 h at 900°C to controlled-impurity helium containing 50 Pa H₂/5 Pa CO/5 Pa CH₄/ <0.05 Pa H₂O (500 μatm H₂/50 μatm CO/50 μatm CH₄/ <0.5 μatm H₂C)

Fig. 16. Bulk carbon concentration for IN 713LC specimens following exposure for 3000 h at 900°C to controlled-impurity helium containing 50 Pa H₂/5 Pa CO/5 Pa CH₄/ <0.05 Pa H₂O (500 μatm H₂/50 μatm CO/50 μatm CH₄/ <0.5 μatm H₂O)

Fig. 17. Bulk carbon concentrations for HK 40 specimens following exposure for 3000 h at 900°C to controlled-impurity helium containing 50 Pa H₂/5 Pa CO/5 Pa CH₄/ <0.05 Pa H₂O (500 μatm H₂/50 μatm CO/50 μatm CH₄/ <0.5 μatm H₂O)

Fig. 18. Bulk carbon concentrations for MA 754 specimens following exposure for 3000 h at 900°C to controlled-impurity helium containing 50 Pa H₂/5 Pa CO/5 Pa CH₄/ <0.05 Pa H₂O (500 μatm H₂/50 μatm CO/50 μatm CH₄/ <0.5 μatm H₂O)

4. DISCUSSION

The second series of corrosion exposures in the surface finish program was intended to experimentally confirm and establish that, within the range of surface finishes normally encountered, surface finish condition does not affect the simulated advanced-HTGR helium corrosion behavior of candidate structural alloys. This general statement encompasses variations in lathe-machined and centerless-ground finishes and the lapped, grit-blasted, and pickled finishes covered under Refs. 1 and 2.

Table 4 presents quantitative data derived from examining the corrosion specimens in this study. Scale characteristics or corrosion behavior varied little over the range of finishes studied. This evidence confirmed the earlier results cited above.

Changes in near-surface chemical activities and/or elemental mobilities, assumed to result when the surface finish is varied, do not greatly influence the controlled-impurity helium corrosion behavior of the test alloys. This program has experimentally reinforced the need to have a surface diffusion barrier to control carburization under these conditions. Good, inherent carburization resistance for alloy IN 100 can be attributed to the formation of a protective Al_2O_3 surface scale (Refs. 3 through 6). This adherent and continuous scale protects against carburization. In Run 1 (Refs. 1 and 2), a continuous and adherent Cr_2O_3 surface scale, which formed during preoxidation treatment, protected Alloy 800H and Hastelloy X from carburization. Although these latter scales were not stable under simulated reactor conditions, the transition to more stable scales (Cr_2MnO_4 in these cases) occurred without disturbing the protective qualities of the scales.

TABLE 4
CHARACTERISTICS OF CORROSION BEHAVIOR
AFTER 3000-H EXPOSURES TO A CONTROLLED-IMPURITY HELIUM ENVIRONMENT

Alloy	Surface Condition (μm)	Surface Scale Thickness (μm)	Depth of Internal Oxidation (μm)	Depth of Alloying Element Depleted Core (μm)	Carburized Zone Depth (μm)
Alloy 800 H	Machined 0.81	13	37	62	95(a)
	Machined 1.57	13	35	62	84(a)
	Machined 3.68	13	35	64	98(a)
	Ground 0.20	10	78	81	87(a)
	Ground 0.86	12	73	73	104(a)
	Ground 1.63	11	49	57	99(a)
Hastelloy X	Machined 0.84	6	15	15	142
	Machined 1.85	6	15	15	151
	Machined 3.94	5	14	14	160
	Ground 0.10	8	15	15	223
	Ground 0.91	8	16	16	214
	Ground 1.14	8	17	17	218
Inconel 617	Machined 1.63	8	33	54	171(a)
	Machined 3.05	9	32	56	187(a)
	Ground 0.20	6	26	40	167(a)
	Ground 0.66	9	29	41	227(a)
	Ground 0.91	5	24	38	117(a)
IN 100	Ground 0.18	4	23	32	--
	Ground 0.76	4	22	30	--
	Ground 0.77	3	27	35	--
IN 713LC	Ground 0.13	6	25	59	365
	Ground 0.61	6	36	36	643
	Ground 0.62	4	32	59	532
HK 40	Machined 0.81	4	7	17	246
	Machined 1.27	6	14	21	140
	Machined 2.79	7	20	24	140
	Ground 0.10	8	20	24	124
	Ground 0.81	10	25	30	175
	Ground 0.91	8	21	23	214
Inconel MA 754	Machined 0.97	3	11	11	--
	Machined 1.24	4	10	10	--
	Machined 3.18	4	9	9	--
	Ground 0.15	4	11	11	--
	Ground 1.02	3	9	9	--
	Ground 1.04	3	9	36	--

(a) Matrix carbide precipitation depth; grain boundary carbide precipitation depth extended to the center of the specimen.

Apparently, varying the surface finish did not help control the carburization of candidate alloys under simulated advanced-HTGR environment conditions. However, the formation of a continuous and adherent preoxidized surface scale can minimize the carburization normally experienced by the wrought high-temperature alloys (Alloy 800H and Hastelloy X). Optimizing the preoxidation conditions is expected to be a viable way to control carburization in Inconel 617, an alloy which displays adequate high-temperature mechanical properties for a lower-temperature (850°C) intermediate heat exchanger design in the advanced HTGR.

5. CONCLUSIONS

1. Varying the lathe-machined and centerless-ground surface finishes did not significantly affect the controlled-impurity helium corrosion behavior of seven candidate structural alloys.
2. The availability of reactive gaseous impurity species and/or the dissociation characteristics of these impurities, present in the helium, controls the simulated advanced-HTGR helium corrosion behavior of these alloys.

Also from Run 1 (Refs. 1 and 2) and Run 2 results, the following point may be concluded:

3. Oxides, when formed in situ (e.g., Al_2O_3 on IN 100) or under controlled environmental conditions (e.g., preoxidation of Alloy 800H and Hastelloy X), can be protective, forming effective diffusion barriers against carburization.

6. REFERENCES

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