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THE EFFECT OF HOT SALT ON THE MECHANICAL PROPERTIES OF SEVERAL SUPERALLOYS

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16. ABSTRACT

The effect of solium chloride on unstressed, transverse, tensile, metal specimens at elevated temperatures has been determined. Results indicate, under the conditions of this test, that the mechanical properties of Inconel 718, Rene' 41, Titanium base alloy 13V-11Cr-3Al, Hastelloy X, HS25 (L605), HS188, and TDNiCr suffer degradation in tensile strength and ductility due to hot-salt exposure.

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THE EFFECT OF HOT SALT ON THE MECHANICAL PROPERTIES OF SEVERAL SUPERALLOYS

INTRODUCTION

The ability to withstand elevated temperature and perform well in an oxidizing atmosphere is characteristic of some superalloys. Superalloys Inconel 718, Rene' 41, HS25 (L605), HS 188, Hastelloy X, TDNiCr and Ti-13V-11Cr-3Al are used extensively for turbine blades and vanes, discs, pressure tanks, combustion chambers, fasteners, jet stacks, jet combs, valves and after burners because they meet the requirements of the space and aircraft industries. Until just a few years ago the effect of salt (sodium chloride-NaCl) on various alloys at elevated temperature had not received much attention, but when the effect of this chemical on titanium was found recently, other alloys quickly came under scrutiny. In this study, unaged and aged, flat, unstressed, transverse, tensile specimens, uncoated and coated with measured amounts of salt, were exposed in an air furnace to elevated temperature. The effect of various amounts of salt on the mechanical properties of these alloys was evaluated.

EXPERIMENTAL PROCEDURE

Flat, unstressed, transverse, tensile specimens (Figure 1) made from 0.0381 cm (0.015 inch) thick sheet of each alloy, with the exception of 0.0127 cm (0.050 inch) thick sheet of Ti-13V-11Cr-3Al, were used in this study. Before testing, some of the alloys were thermally treated (see Table II). Mechanical properties were measured at room temperature on pre- and post-exposure specimens in all conditions tested, (solution treated annealed, aged, aged plus 48 hours at elevated temperature with and without NaCl deposits). All alloys were evaluated at 1033°K (1400°F) unless the alloy was developed for use at a lower temperature, or the effect of lowering the temperature was to be determined. Specimens were coated on one side only, an area approximately 7.62 x 1.27 cm (3 x 0.5 inch), with NaCl in a fog cabinet using a 5 percent sodium chloride solution. Specimens were removed from the cabinet when the desired salt deposits were obtained. Varying amounts, 0.00006 gm/sq. cm (0.0004 gm/sq. in. - 1.04×10^{-5} inch thick) to 0.09600 gm/sq. cm (0.6200 gm/sq. in. - 0.017 inch thickness), of salt was used in this study, although small amounts 0.00011 gm/sq. cm (0.0012 gm/sq. in. - 3.4×10^{-5} inch thickness) was thought to be more realistic as shown in Table III. McDonnell Douglas Corporation, in their Second Quarterly Report under contract NAS8-27270, used concentrations of salt 0.0005 - .001 inch thick on their specimens [1]; however, North American Rockwell in their report SCTR-71-18 used a thickness of 0.015 inch [2]. Specimens racked edgewise were placed in a muffle furnace in air at the desired elevated temperature and left for the duration of the test (48 hours). Post exposure mechanical properties on the specimen were determined at room temperature.

RESULTS AND DISCUSSION

The compositions of the alloys evaluated are given in Table I. Typical analysis is given for Inconel 718 where the specific composition was not determined. The heat treatments and pre- and post exposure mechanical properties with percent loss in ultimate tensile strength are given in Tables II and III.

The results of this evaluation indicate that sodium chloride in very small amounts (0.00017 gm/sq. cm - 0.0011 gm/sq. in.) in an air environment at elevated temperature has a detrimental effect upon the unstressed mechanical properties and surfaces of all alloys that were investigated in this program.

INCONEL 718

Inconel 718, a Ni-Fe-Cr base alloy, has a 7 percent loss in tensile strength in the overaged condition, as compared to the normally aged condition. There was no loss in ductility in the overaged material when compared with the aged material free of salt (NaCl). This alloy in the overaged condition showed a tendency to lose tensile strength and ductility when coated with 0.00115 gm/sq. cm (0.0071 gm/sq. in.) of salt (NaCl). As shown in Table III, when the deposits of NaCl became heavier the degradation of properties became more severe, until finally the metal was almost completely destroyed. Figure II reveals the effects of these deposits on this alloy and also shows the effects on the mechanical properties. Oxidation and the presence of NaCl at elevated temperature has a great corrosive effect on the surface, leaving it pitted and with heavy scaling in the salted area.

RENE'41

Rene' 41 is a precipitation hardenable nickel base alloy which is designed for high temperature application. Table III indicates very little difference in the aged and overaged mechanical preperties, with the exception of a small drop in ductility in the overaged material. Salted specimens at 1033°K (1400°F) lost 14 percent in tensile strength and the ductility was reduced to nearly one-half as compared to the overaged specimen without salt. The combination of salt and lower temperatures 867°K (1100°F) and 700°K (800°F) had apparently no effect on this alloy. The only visible effects of the salt was that of an etched appearance. Oxidation however turned the entire specimen a dark gray at these temperatures. Figure III shows scanning electron micrographs of Rene' 41 which has been evaluated with and without salt deposits at elevated temperature. The effect of the salt can be readily seen by the grain separation on the salted specimen. This separation of the grains resulted in a loss of mechanical properties of this alloy (see Table III).

HASTELLOY X, HS25 (L605), HS188 and TDNiCr

Hastelloy X, a nickel base alloy, HS25 (L605), a ductile cobalt base alloy, HS188, a similar alloy to HS25 (L605) but containing twice the nickel content, and TDNiCr, a dispersion strengthened alloy, are usually used in the solution annealed condition. When these (non-heat treatable) solution annealed alloys were subjected to an elevated temperature of 1033°K (1400°F) for 48 hours there was an effect on their ambient temperature mechanical properties. This is to be expected for most non-heat treatable alloys. With small deposits (0.00017 gm/sq. cm - 0.0011 gm/sq. in.) of salt (NaCl) the mechanical properties were further reduced. Hastelloy X salted specimens had a loss in tensile strength and ductility of 4 and 26 percent when compared with those having no salt. HS25 (L605) specimens behaved as did the Hastelloy X in that they lost also in tensile strength (7 percent) and ductility (16 percent) when compared with specimens containing no salt.

TDNiCr was an exception for a non-heat treatable alloy in that its mechanical properties were not greatly affected by the exposure to elevated temperatures and to small amounts of salt at 1033°K (1400°F). As the salt deposits became larger tensile strength and ductility began to suffer loss. At the 0.00017 - 0.00050 gm/sq. cm (0.00085 - 0.00280 gm/sq. in.) salt levels, there was very little loss in properties, but at the 0.00240 - 0.00370 gm/sq. cm (0.01540 - 0.02550 gm/sq. in.) levels there was a tensile strength loss of 9 and 11 percent and ductility loss of 22 and 25 percent when compared with unsalted specimens. Although tensile strength and ductility suffered from the effects of salt deposits, there was no effect on the yield strength of this material from either the salt or temperature.

Salt had its effect on HS188 in that it reduced the tensile strength and ductility 6 and 39 percent with salt deposits of 0.00015 gm/sq. cm (0.0010 gm/sq. in.). When the deposits are increased (0.00190 gm/sq. cm - 0.0120 gm/sq. in.), the tensile strength and ductility are further decreased to 11 and 62 percent. Like TDNiCr material, the yield strength of the HS188 was not reduced by either the salt or temperature at 1033°K (1400°F). These results may be seen in Table III.

All specimen surfaces of subject materials evaluated in this program suffered surface oxidation at the test temperature. In the NaCl deposited areas there was light pitting and heavy oxidation; these areas of attack can be seen in Figure IV.

Ti-13V-11Cr-3Al

This alloy possesses good mechanical properties in the aged condition, but it is limited in usage because of a narrow temperature range. This alloy should never be subjected to a 1033°K (1400°F) temperature, because at this temperature it becomes contaminated with O, N, and H which destroys its aged properties. With the addition of NaCl deposits at this temperature the mechanical properties are further reduced. In the aged condition with the addition of NaCl deposits (up to 0.00023 gm/sq. cm - 0.00150 gm/sq. in.), there appeared to be no ill effects on the mechanical properties at a workable temperature for this alloy. The oxidation on the specimens tested at 533°K (500°F) was very light. The specimens evaluated at 1033°K (1400°F) had deep pitting and severe scaling in the NaCl affected area, with the entire specimen surface being covered with a black oxide film.

CONCLUSIONS

The results obtained from this study indicate the following:

1) Inconel 718 mechanical properties are very much affected by 0.00115 gm/sq. cm (0.0071 gm/sq. in.) NaCl deposits at elevated temperature 977°K (1300°F). As the NaCl deposits become heavier there is a correspondingly greater loss in tensile strength and in ductility.

2) NaCl deposits of 0.00017 gm/sq. cm (0.0011 gm/sq. in.) on Rene' 41 affect the tensile strength and ductility when the material is heated above the 867°K (1100°F) temperature range.

3) Aging at 1033°K (1400°F) without NaCl deposits reduced the ductility of Hastelloy X, HS25 (L605) and HS188, but had no effect on TDNiCr. The combination of salt (0.00017 gm/sq. cm - 0.0011 gm/sq. in. for alloys Hastelloy X, HS25 (L605), HS188 and 0.00240 gm/sq. cm - 0.01540 gm/sq. in. for TDNiCr) and elevated temperatures resulted in loss of tensile strength and further a decrease in the ductility of these alloys.

4) Titanium base alloy 13V-11Cr-3Al should never be used in the 1033°K (1400°F) temperature range. Salt deposits of 0.00007 - 0.00023 gm/sq. cm (0.00044 - 0.00150 gm/sq. in.) had no effect on this alloy's properties when properly aged and subjected to a workable temperature of 533°K (500°F).

5) If small deposits (0.00017 gm/sq. cm - 0.0011 gm/sq. in.) of salt (NaCl) at a moderately elevated temperature 1033°K (1400°F) had an effect on the mechanical properties of unstressed material, it would be logical to assume that this effect would be greater at higher temperatures. If this be true, then materials that are to be used at elevated temperatures and in a stressed condition must be as free as possible from NaCl concentration. Additional studies should be conducted for specific cases.

REFERENCES

1. Davis, J. W.: "The Corrosion and Stress Corrosion Susceptibility of Several High Temperature Alloys," Second Quarterly Report. Contract No. NAS8-27270, McDonald Douglas Corporation, December, 1971.

2. Paton, N. E., Roberton, W. M., Mansfeld, F.: "High Temperature Behavior of Superalloys Exposed to Sodium Chloride," Technical Report SCTR-71-18, North American Rockwell, November, 1971.

APPENDIX A

Conversion of U. S. Customary Units to SI Units

The International System of Units (SI) was adopted by the Eleventh General Conference on Weights and Measures in 1960. Conversion factors for the units used herein are given in the following table.

Physical Quantity	U. S. Customary Unit	Conversion Factors (a)	SI Units (b)
Length	In.	0.0254	meter (m)
Stress	psi	6895	Newton/meter^2 (N/M^2)
Temperature	°F	5/9 (°F+460)	Kelvin (K)

(a) Multiply value given in U. S. Customary Units by conversion factor to obtain equivalent value in SI Unit.

(b) Prefixes to indicate multiple units as follows:

PREFIX	MULTIPLE
centi (c)	10^{-2}
mega (M)	10^{6}

TABLE I

CHEMICAL ANALYSIS OF METAL ALLOYS

ALLOY	SOURCE AND HEAT NO.		FORM
TDNiCr	Fansteel	3514	Sheet
Rene' 41	Universal Cyclops	L 1477-K2	Sheet
Hastelloy X	Cabot	2600-9-4954	Sheet
HS 188	Cabot	1880-9-0150	Sheet
HS25 (L605)	Cabot	1860-9-1349	Sheet
Ti-13V-11Cr-3Al	Timet	G9778	Sheet
Inconel 718	Unknown		Sheet

COMPOSITION WEIGHT %

ALLOY	C	S	Cr	ThO_2	Ni	Co	Mo	Al	Ti	B	Fe	Mn	Si	W	P	N	V	OTHER
TDNiCr	.0156	.0026	19.20	1.98	Bal.													
Rene' 41	.072	.005	18.52			10.64	9.55	1.46	3.02	.006	0.75	.03	.04					
Hastelloy X	.07	.005	21.57		Bal.	1.96	9,04			.002	18.79	.61	.35	0.63	.018			
HS 188	.10	.003	21.40		22.3	Bal.					1.48	.62	.25	14.54	.008			
HS25 (L605)	.11	.001	19.45		9.95	Bal.					2.57	1.46	.01	15.30	.012			
Ti-13V-11Cr-3Al	.028		11.3					3.0			.02					.02	13.6	(2)
Inconel 718 (1)	.10	.015	19.00		52.0		3.05	0.6	1.05		Bal.	.40	.45		.15			(3)

Notes:
(1) Typical Analysis
(2) H(.007) O (.13)
(3) Cu(0.30) Cb+Ta(5.15)

TABLE II

HEAT TREATMENT OF ALLOYS

<u>Inconel 718</u>

Material received in the solution annealed condition. Aged ten hours at 977°K (1300°F), furnace reset for 922°K (1200°F) and aged for total aging time of 20 hours.[(1) (2)]

<u>Rene' 41</u>

Material received in the solution annealed condition 1339°K (1950° F). Aged 16 hours at 1033°K (1400°F).[(1) (2)]

<u>Ti-13V-11Cr-3Al</u>

Material received in the solution annealed condition. Aged twenty-four hours at 755°K (900°F).[(1) (2)]

<u>HS25 (L605)</u>

Material tested as received; solution annealed at 1505°K (2250°F); water quenched by producer.

<u>Hastelloy X</u>

Material tested as received; solution annealed at 1450°K (2150°F); rapid cooled in a dry hydrogen atmosphere by producer.

<u>HS188</u>

Material tested as received; solution annealed at 1450°K (2150°F); water quenched by producer.

<u>TDNiCr</u>

Material tested as received (in the stress relieved condition).

Notes: (1) Aged by MSFC.
(2) Recommended Thermal Treatment.

TABLE III

EFFECT OF SALT AND TEMPERATURE ON UNSTRESSED PRE- AND POST EXPOSURE MECHANICAL PROPERTIES

CONDITION OF MATERIAL	# OF SPEC.	SALT		U.T.S.		Y.S.		% El	% LOSS
		gm/sq cm	gm/sq. in	MN/m^2	ksi	MN/m^2	ksi	5.04 cm (2 in)	U.T.S.
INCONEL 718									
Aged (1) (2)	3	NO	NO	1386	201	1124	163	20.5	-
Aged (1) (2) + 48 hrs.	1	NO	NO	1289	187	979	142	19.5	7
@ 977°K (1300°F)	1	0.00064	0.0004	1296	188	1000	145	21.0	-
	2	0.00011	0.0012	1310	190	1020	148	18.7	-
	1	0.00012	0.0013	1303	189	1014	147	18.7	-
	1	0.00115	0.0071	1241	180	972	141	17.0	4
	1	0.00280	0.0192	1234	179	965	140	10.0	4
	1	0.01580	0.1000	903	131	807	117	1.5	30
	1	0.09600	0.6200	434	63	---	---	0.5	66
RENE' 41									
As received solution treated	2	NO	NO	945	137	434	63	47.5	
Aged (1) (2)	2	NO	NO	1427	207	1034	150	22.5	
Aged 48 hrs. @ 1033°K (1400°F)	2	NO	NO	1441	209	1034	150	21.0	
Aged (1) (2) + 48 hrs. @ 1033°K (1400°F)	2	NO	NO	1544	224	1158	168	17.5	
Aged (1) (2) + 48 hrs. @ 1033°K (1400°F)	2	0.00017	0.0011	1324	192	1069	155	9.25	14

TABLE III (CONTINUED)

CONDITION OF MATERIAL	# OF SPEC.	SALT		U.T.S.		Y.S.		% El	% LOSS
		gm/sq cm	gm/sq in	MN/m^2	ksi	MN/m^2	ksi	5.04 cm (2 in)	U.T.S.
TDNiCr									
As received solution treated	2	NO	NO	820	119	531	77	19.0	
As received solution treated + 48 hrs. @ 1033°K (1400°F)	2	NO	NO	800	116	531	77	18.0	
As received solution treated + 48 hrs. @ 1033°K (1400°F)	1	0.00017	0.00085	779	113	517	75	19.5	-
As received solution treated + 48 hrs. @ 1033°K (1400°F)	1	0.00050	0.00280	786	114	524	76	19.5	-
As received solution treated + 48 hrs. @ 1033°K (1400°F)	1	0.00240	0.01540	724	105	503	73	14.0	9
As received solution treated + 48 hrs. @ 1033°K (1400°F)	1	0.00370	0.02550	710	103	524	76	13.5	11
HS 188									
As received solution treated	2	NO	NO	1020	148	496	72	52.0	
Aged 48 hrs. @ 1033°K (1400°F)	2	NO	NO	972	141	530	77	43.0	
Aged 48 hrs. @ 1033°K (1400°F)	2	0.00015	0.0010	910	132	503	73	26.3	6

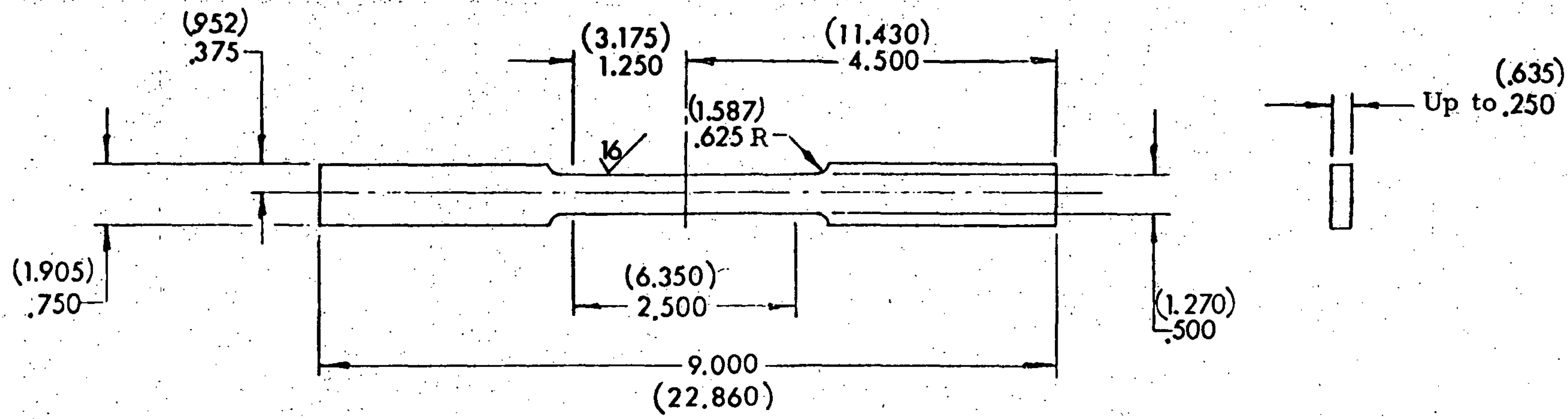
TABLE III (CONTINUED)

CONDITION OF MATERIAL	# OF SPEC.	SALT		U.T.S.		Y.S.		% El	% LOSS
		gm/sq cm	gm/sq in	MN/m^2	ksi	MN/m^2	ksi	5.04 cm (2 in)	U.T.S.
RENE' 41 (CONTINUED)									
Aged (1) (2) + 48 hrs. @ 867°K (1100°F)	2	0.00015	0.0010	1448	210	1076	156	20.25	-
Aged (1) (2) + 48 hrs. @ 700°K (800°F)	2	0.00008	0.0005	1475	214	1062	154	24.75	-
HASTELLOY X									
As received solution treated	2	NO	NO	800	116	379	55	50.0	-
As received solution treated + 48 hrs. @ 1033°K (1400°F)	2	NO	NO	855	124	407	59	28.5	-
As received solution treated + 48 hrs. @ 1033°K (1400°F)	2	0.00017	0.0011	820	119	400	58	21.0	4
HS25 (L605)									
As received solution treated	2	NO	NO	951	138	490	71	30.0	-
As received solution treated + 48 hrs. @ 1033°K (1400°F)	2	NO	NO	841	122	510	74	21.5	-
As received solution treated + 48 hrs. @ 1033°K (1400°F)	2	0.00017	0.0011	786	114	524	72	18.0	7

TABLE III (CONTINUED)

CONDITION OF MATERIAL	# OF SPEC.	SALT		U.T.S.		Y.S.		% El	% LOSS
		gm/sq cm	gm/sq in	MN/m^2	ksi	MN/m^2	ksi	5.04 cm (2 in)	U.T.S.
HS 188 (CONTINUED)									
Aged 48 hrs. @ 1033°K (1400°F)	1	0.00190	0.0120	862	125	524	76	16.5	11
Aged 48 hrs. @ 1033°K (1400°F)	1	0.00240	0.0144	862	125	552	80	16.0	11
Ti-13V-11Cr-3Al									
As received solution treated	2	NO	NO	1034	150	1034	149	14.0	
Aged 24 hrs. @ 755°K (900°F) (1) (2)	2	NO	NO	1441	209	1351	196	4.0	
Aged 48 hrs. @ 1033°K (1400°F)	2	NO	NO	986	143	986	143	3.0	
Aged 24 hrs. @ 755°K (900°F) (1) (2) + 48 hrs. @ 1033°K (1400°F)	2	0.00018	0.00115	758	110	758	110	5.25	47
Aged 24 hrs. @ 755°K (900°F) (1) (2) + 48 hrs. @ 533°K (500°F)	1	0.00023	0.00150	1469	213	1358	197	6.0	-
Aged 24 hrs. @ 755°K (900°F) (1) (2) + 48 hrs. @ 533°K (500°F)	1	0.00007	0.00044	1482	215	1372	199	4.0	-

Notes (1) Aged by MSFC
(2) Recommended Thermal Treatment



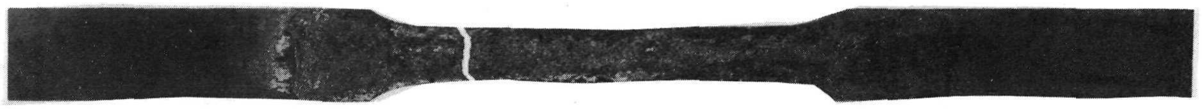
Dimensions In Inches
Dimensions in Centimeters ()

NOTE: Overall dimension will vary with the strength and the desired stress level

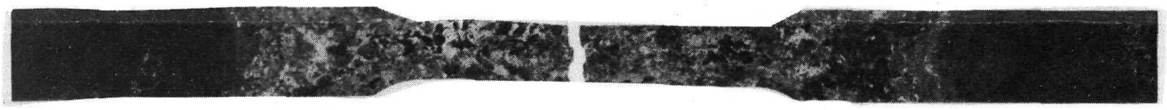
FIGURE 1 - FLAT TENSILE SPECIMEN CONFIGURATION

48 HOURS AT 977°K (1300°F)

NO SALT



0.00115 gm/cm² (0.0071 gm/sq. in)

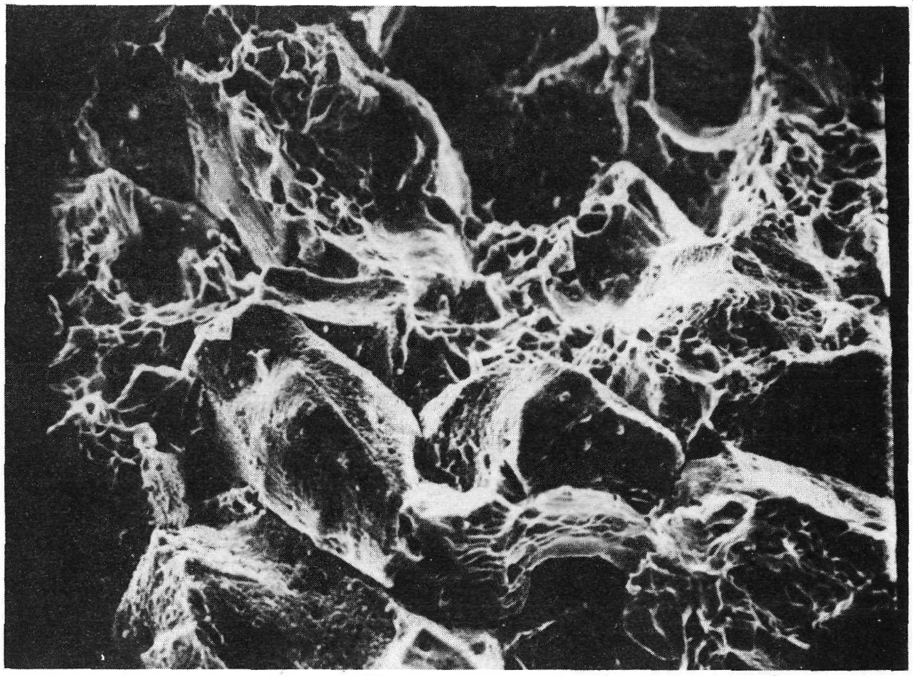


0.0960 gm/cm² (0.6200 gm/sq. in.)

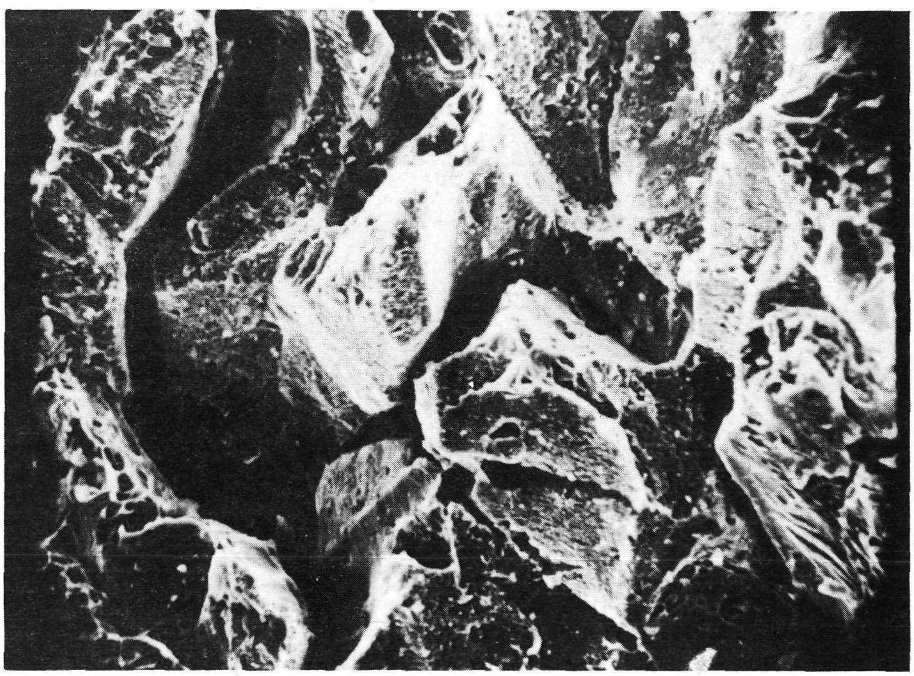
MECHANICAL PROPERTIES

SALT DEPOSITS gm/cm² (gm/sp. in.)	TS	YS	%EL
ORIGINAL (NOT HEATED)	200	163	20
NO SALT	187	142	20
0.00115 (0.0071)	180	140	17
0.0960 (O.6200)	63	—	0.5

FIGURE 2 HOT SALT EXPOSURE INCONEL 718



NO SALT 1033°K (1400°F) SEM 1000X



WITH SALT 1033°K (1400°F) SEM 1000X

FIGURE 3 - RENE' 41

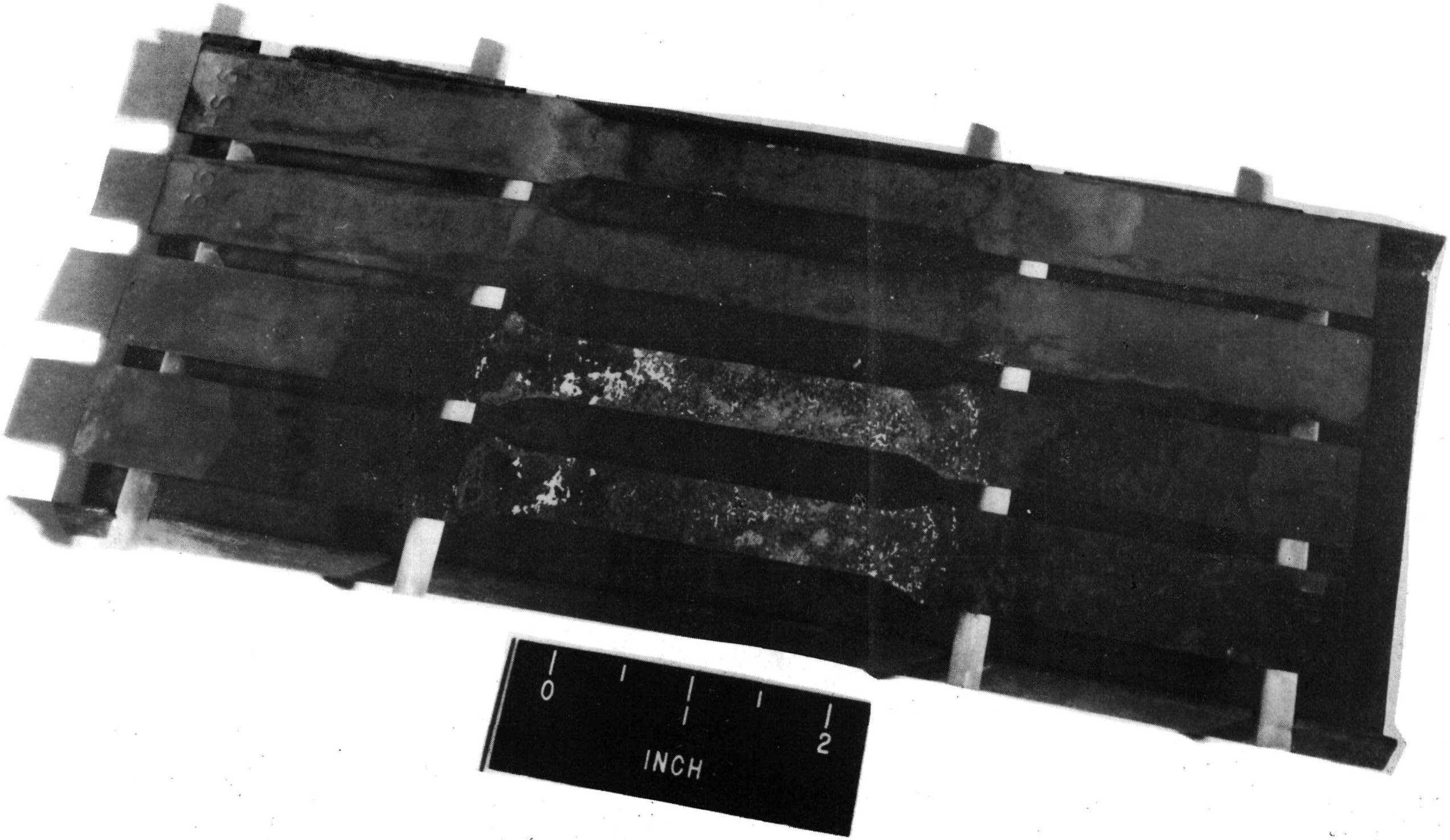


FIGURE 4 - SALT DEPOSITED AREAS SHOWING ATTACK ON ALLOYS TDNiCr AND HS188

APPROVAL

THE EFFECT OF HOT SALT ON THE MECHANICAL PROPERTIES OF SEVERAL SUPERALLOYS

By

Eli E. Nelson

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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