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SEMI-FIN REPORT ON THE CORROSION
RESISTANCE OF SEVERAL ALLOYS IN AN HF-H₂O
ATMOSPHERE AT HIGH TEMPERATURES

By
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August 3, 1950

Mallinckrodt Chemical Works

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For The Atomic Energy Commission
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Chief, Declassification Branch

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SEMI-FINAL REPORT ON THE CORROSION RESISTANCE OF SEVERAL ALLOYS
IN AN HF-H₂O ATMOSPHERE AT HIGH TEMPERATURES*

By C. F. Ritchie and G. K. Teter

INTRODUCTION

This report covers macroscopic observations upon various alloys exposed to an HF-H₂O atmosphere at 1070° F. This report does not cover those alloys previously reported as failures; but does cover those alloys which have failed and those showing exceptional promise, not heretofore reported.

PURPOSE

The aim of this testing program was to find the best metal or alloy that could be used as a material of construction for UF₄ process equipment.

REFERENCE

The corrosion resistance of other alloys, tested in an HF-H₂O atmosphere at 1070° F, may be had by referring to MCW Reports No. 150, 161, 178, 203, and 249.

SUMMARY

The alloys tested can best be recorded if they are put in groups, each group having similar principal constituents. The groups, and their respective alloys, are as follows:

Group A. The Cobalt Alloys

1. S-590	4. N-155 (Hastelloy E)
2. S-816	5. Multimet 95
3. L-605	

Group B. The Nickel-Iron and Chrome-Iron Alloys

1. No. 36 Alloy	4. No. 52 Alloy
2. No. 46 Alloy	5. Radiohm
3. No. 42 Alloy	

Group C. The Nickel-Chrome Alloys

1. Electro-Alloy No. 3	5. 25-16-6
2. S-588	6. D-10
3. Inconel-G (cast)	7. Inconel-R (rolled)
4. N-238	8. Chromel-P

Group D. The Chrome-Nickel Alloys

1. Hastelloy C	3. GT-45
2. 19-9 DL	4. 19-9 WMo

*Work performed under Contract No. W-7405 eng 29.

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Group E. The Copper-Nickel Alloys and Copper Coated Alloys

1. U. S. Mint 5¢ piece	4. Copper plated Inconel
2. Super Nickel	5. 326 Monel
3. Copper plated Monel	

Group F. The Aluminum Alloys and Aluminum Coated Alloys

1. Calorized Inconel
(20 pieces)	4. Al (3S-H)
2. Copper plated Monel,
calorized	5. 132 Aluminum
3. Copper plated Inconel,
calorized	6. Al (52S-1/4H)
	7. Al (2S-H)

Group G. The Precious Metal Alloys

1. 95 Pt-5 Ir	3. 95.5 Pd-4.5 Ru
2. 95 Pd-5 Au on a
Ni (Mn) base	4. 60 Pd-35 Ag-5 Au
	5. 60 Pd-40 Cu

Group H. Miscellaneous Alloys

1. Titanium
2. Metamic
3. Z-Nickel

To date the most promising alloys (of those tested for this report) have been the Nickel-Chrome alloys which are high in Nickel, Illium-R, Chromel-P Illium G, 25-16-6, D-10, and Electroalloy No. 3, all of which have a Ni-Cr ratio of 1.56 to 1 or higher, have given very good results. Illium-R, an Illium Corporation (Burgess-Parr) product, is the superior alloy of the five.

Some members of the precious metal alloy, Group G, have shown exceptional resistance. The best in the group, 95 Pt-5 Ir alloy, has been under test conditions for 4400 actual hours and still shows no sign of scaling or embrittlement. However, these alloys are very expensive and have a low creep strength.

Three Cu-Ni alloys have shown themselves to be resistant to HF-H₂O at 1070° F, though not as much as the Ni-Cr alloys previously mentioned. These alloys, Super Nickel, a 75 Cu-25 Ni alloy (a 1948 5¢ U. S. Mint Issue), and 326 Monel have a low creep strength and so would be used where structural strength is not a prerequisite, i.e., rotary valves or as a liner for reactors, etc.

The remaining alloys recorded have failed or started to fail at the writing of this report.

The cobalt alloys, the Ni-Fe, the Cr-Fe and some of the Cr-Ni alloys were tested because they are relatively new in the metal alloy field and/or because they have very high tensile strengths at elevated temperatures.

METHOD OF TESTING

The method of testing was the same for all the alloys. Each alloy was stamped with some identifying symbol and placed in a small test box containing UO₂. The test sample was placed in the Plant 4 green salt reaction trays and subjected to various concentrations of HF-H₂O (from 60 to 100 per cent HF) at 1070° F during a 20-hr reaction period. The reaction trays were then air cooled to room temperature and the test boxes removed for inspection. This procedure was followed on an average of three times a week for each alloy until the alloy has failed or been rejected.

It should be remembered that all reference in this report to hours an alloy has been tested refers to the actual number of hours under the test conditions of HF-H₂O at 1070° F. In some instances, prior reports refer to weeks of testing which means that, on an average, the specimen was under the above test conditions 60 hr a week.

At various times the alloys were examined for hardness of scale by scratching with a knife and for scale tenacity and embrittlement by bending the sample 90 deg and back. Those samples which shed their scale (while in the test boxes) or became embrittled were removed from service.

TESTING RESULTS

The hours recorded after each alloy is the hours the alloy has been under test conditions. See tabulation at the end of this report for data on the manufacturer and the compositions of the metals.

Group A. The Cobalt Alloys

1. S-590, 940 hr. A few small, shallow pits have formed. The scale was thin and semi-hard, fairly easy to scratch. A small amount of fine scale was shed when the sample was bent. The alloy broke with a 60 deg (and back) bend. The sample was removed from service.
2. S-816, 940 hr. The scale formed on this alloy was thin and hard. Some shallow pitting was observed though it was not as bad as for S-590. A small amount of scale was shed when the sample was bent. The alloy broke with a 90 deg bend. The sample was removed from service.
3. L-605, 940 hr. This specimen had a very hard black scale which shed slightly when bent. No embrittlement has been noticed. The sample is still being tested.
4. N-155 (Hastelloy E), 360 hr. A thin semi-hard black scale has been formed. The scale shed slightly when the sample was bent. No embrittlement has been noticed. The sample is still being tested.
5. Multimet 95, 940 hr. A very hard, black scale has formed on this alloy. The scale shed slightly when the sample was bent. No embrittlement has been noticed. The sample is still being tested.

Group B. The Ni-Fe and Cr-Fe Alloys

1. No 36 Alloy (Nilvar), 80 hr. The test alloy became very brittle, though there was little change in its color throughout the test period. The sample was removed from service.
2. No. 46 Alloy, 140 hr. The sample became very brittle. The metal looked as if it had been scorched. The sample was removed from service.
3. No 42 Alloy, 140 hr. There was little change in color of this alloy, but when bent (after 80 hr under test conditions) it flaked quite badly. At the end of the test period the alloy became very brittle. The sample was removed from service.
4. No 52 Alloy, 140 hr. This alloy did not become as embrittled as the other alloys in this group but it flaked badly when bent. The alloy was removed from service.
5. Radiohm, 80 hr. At the first exposure the alloy was badly rusted. With subsequent exposures the rust-colored scale flaked off very badly. The alloy was removed from service.

Group C. The Ni-Cr Alloys

1. Electro-Alloy No. 3, 1660 hr. This alloy has a heavy black enamel-like scale. It is very hard to scratch. All identification symbols and edges are still very clear and sharp. The alloy is too thick to bend (cast). The sample is still being tested.
2. S-588, 1420 hr. The scale on this alloy was black and easily scratched. The sample broke with a 90 deg bend and was removed from service therefore.
3. Illum-G, 1080 hr. After the first 20 hr of exposure a smooth, black, very hard adherent scale was formed. To date there has been no change. The alloy was cast so no bend test was given. This alloy, and Illum-R (see below) have been the best alloys yet tested. The alloy is still being tested.
4. N-238, 940 hr. A semi-hard, thin scale has been formed on this alloy. The scale flakes off when the sample is bent. No embrittlement has been noticed. The alloy is still being tested.
5. 25-16-6, (sold as "16-25-6" alloy) 780 hr. This alloy has stood up surprisingly well, especially in view of the fact that it is a modified stainless steel. A thin, greyish black, very hard scale has been formed. The edges and machine markings are still very sharp. The sample is too thick to give a bend test. The alloy is still being tested.
6. D-10, 700 hr. The alloy is very similar to Illum-G, it formed a thin, black, very hard scale with the first exposure which then remained, apparently unchanged up to the time of this report. The alloy was cast and therefore not subjected to a bend test. The alloy is still being tested.

7. Illium-R (rolled), 960 hr. A thin black and greenish-black scale has been formed. The scale is adherent when the sample is bent but is not as hard as that of Illium-G. No embrittlement noticed. This alloy has been one of the best tested. It is still being tested. Based upon preliminary tests, the Illium-R has been purchased for certain large-scale work.

8. Chromel-P, 2880 hr. This alloy has changed little since last reported. A smooth adherent scale is formed which sheds very little with bending. A slight amount of intergranular corrosion at the bend. No embrittlement noticed.

Group D. The Cr-Ni Alloys

1. Hastelloy C, 940 hr. A very hard, thin, tenacious scale has been formed. This black scale is spotty; several 'clean' areas remain. The sample broke with a 60 deg bend. The alloy is still being tested, but will be eliminated shortly.

2. 19-9 DL, 260 hr. A black, thin scale flaked off the sample while in the test box. Some areas were heavily pitted. The alloy was removed from service.

3. GT-45, 180 hr. A heavy scale was formed. This scale flaked off considerably while in the test box. The alloy was removed from service.

4. 19-9 WMo, 20 hr. A 19-9 stainless steel with W and Mo added. While in the test box the sample flaked very badly. Successive layers of scale were formed. The alloy was removed from service.

Group E. The Cu-Ni Alloys and Cu coated Alloys

1. 1948 5¢ U. S. Mint, 2000 hr. All markings were still very clear. There was no evidence of the light-colored scale flaking off. The scale was soft and adherent. The specimen was lost — possibly to a slot machine.

2. Super Nickel, 2140 hr. A soft, adherent scale was formed. No embrittlement noticed. The alloy is still being tested. Some intergranular corrosion noted at the bend.

3. Cu plated Monel, 2140 hr. The copper plating had corroded off the Monel base. The sample was removed from service.

4. Cu plated Inconel, 2140 hr. The copper plating had corroded off the Monel base. The sample was removed from service.

5. 326 Monel, 1400 hr. This alloy has changed very little since last reported. The alloy is still very clean looking. The scale is adherent and easily scratched. The alloy is too heavy to give a fair bend test. It is still being tested.

Group F. The Al Alloys and Al coated Alloys

1. Calorized Inconel, 2160 hr. These samples (some 20 of them) had flaked the calorizing. The samples were removed from service.

2. Cu plated Monel—calorized, 1720 hr. The calorizing started to chip off at the edges and the Cu plating erupted through the face calorizing. The sample was removed from service.

3. Cu plated Inconel — calorized, 1720 hr. The calorizing started to chip off at the edges and the Cu plating erupted through the face calorizing. The sample was removed from service.

4. Al (3S-H), 1380 hr. This alloy expanded a great deal and any portion that had previously been bent corroded quite badly. The sample was removed from service. Despite this feature of dimensional instability, an Al liner was employed in one of our early continuous green salt tubes with fair success.

5. 132 Aluminum, 20 hr. This alloy became very badly corroded and swollen. A large portion of the sample had been reduced to a black dust. The sample was removed from service.

6. Al (52S-1/4H). This alloy gave about the same results as Al (3S-H).

7. Al (2S-H). This alloy gave about the same results as Al (3S-H).

Group G. The Precious Metal Alloys

1. 95 Pt-5 Ir, * 4400 hr. This alloy is still very new looking, though there has been some slight

*Purchased from Baker and Co. Inc., Newark, N. J.

distortion. No visible scale and no embrittlement has been noticed. This is the best alloy tested of Group G. The alloy is still being tested

2. 95 Pd-5 Au* on a Ni (Mn) base, 4340 hr. This alloy now has a dull finish, a thin adherent scale. No embrittlement has been noted. The portion which is buried in the UO_2 is noticeably darker than the exposed portion. The alloy is being further tested. (The Mn-Nickel (2 per cent Mn) base shows considerable deterioration, as would be expected.)

3. 95.5 Pd-4.5 Ru,* 4340 hr. This alloy broke at a weld. There is a dull adherent film formed. The alloy is becoming embrittled, but is still being tested.

4. 60 Pd-35 Ag-5 Au,† 4140 hr The alloy has a dull adherent film on it. No embrittlement noted. The alloy is still being tested

5. 60 Pd-40 Cu,† 4140 hr. This alloy has formed a dull adherent film. The alloy is becoming embrittled, but the sample is still being tested

Group H. Miscellaneous Alloys

1. Titanium, 220 hr. Throughout the test period the alloy had a fine, powdery film on its surface. The sample was rapidly corroding and becoming very brittle. The alloy was removed from service.

2. Metamic, 220 hr. This sample had been flaking slightly before it was lost.

3. Z-Nickel, 560 hr. A thin, black, very hard scale has been formed. The sample shows embrittlement, it broke with a 90 deg bend. The scale is adherent on bending. The alloy is still being tested, but will be eliminated shortly

Please refer to the appended table for the compositions and supplier of each of the alloys.

*Purchased from Baker and Co. Inc., Newark, N. J.

†Purchased from Central Plate Division of Metals & Controls Corporation, Attleboro, Mass

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Supplier and Composition of the Tested Alloys

Group	Alloy	Supplier	Approximate Composition, Per Cent													
			Ni	Cr	Fe	Cu	Al	Mo	W	Cb	Mn	Si	Co	Mg	Ti	C
A	S-590*	Allegheny-Ludlum	19.4	20.9	26.5			4.3	3.9	3.9	1.7	0.7	19.3			0.4
	S-816*	Allegheny-Ludlum	20.2	19.8	4.1			4.3	4.3	3.8	0.5	0.4	42.3			0.4
	L-605	Haynes-Stellite	10.0	20.0	9.0				15.0				46			
	N-155	Alleghney-Ludlum	20.0	20.0	31.0			3.0			1.5	0.7	20		2.2	0.4
	Multimet 95	Haynes-Stellite	20.0	20.0	34.0				2.0	1.0	3.0		20			
B	No. 36 Alloy*	Driver-Harris Co.	36.0		64.0											
	No. 46 Alloy*	Driver-Harris Co.	46.0		54.0											
	No. 42 Alloy*	Driver-Harris Co.	42.0		58.0											
	No. 52 Alloy*	Driver-Harris Co.	52.0		48.0											
	Radiohm*	Driver-Harris Co.		16.5	78.5		5.0									
C	Electro-Alloy No. 3	Amer. Brake Shoe Co.	59.0	14.0	6.0			16.0	4.0							
	S-588*	Alleghney-Ludlam	19.7	18.3	47.3			4.0	3.64	4.4	1.32					
	Illium-G (cast)	Illium Corp.	62.0	21.0	6.0	4.0		6.0								
	N-238	Haynes-Stellite	45.0	22.0	22.0			6.0	2.0	2.0						
	25-16-6	Timken Bearing Co.	25.0	16.0	52.0			6.0			1.0					0.1
	D-10	Duriron Co., Inc.	66.6	23.3	2.7	3.0		2.4	0.2		0.8	0.8				0.3
	Illium-R (rolled)	Illium Corp. (Burgess-Parr)	62.0	21.0	8.0	3.0		5.0								
	Chromel-P	Hoskins Mfg. Co.	90.0	10.0												
D	Hastelloy C	Haynes-Stellite	24.0	28.0	6.0	17.0		19.0	5.0							
	19-9 DL*	Allegheny-Ludlum	9.0	19.0	67.3			1.3			0.6	0.7				0.3
	GT-45*	Allegheny-Ludlum	13.1	17.7	61.0	2.5		2.6			1.8	0.5		0.2		
	19-9 WMo*	Universal Cyclops Steel Corp.	8.5	19.0	68.1			0.4	1.4	0.6	0.6	0.9		0.5		0.1
	U. S. Mint 5¢ Piece†	U. S. Mint	25.0			75.0										
E	Super Nickel	Amer. Brass	30.0		0.4	69.6										
	326 Monel	International Nickel	40.0			60.0										
F	Al (2S-H)	Alcoa					99.0+									
	Al (3S-H)*	Alcoa					98.8				1.2					
	132 Aluminum*	Fairchild Eng. & Airplane Corp.	2.5			0.8	83.5					12.0		1.2		
	Al (52S-1/4H)	Alcoa		0.25			97.25							2.5	99.+	
H	Titanium*	“Acquired”													99.+	
	Metamic†	Linde Air Products		87.0	(13% Al ₂ O ₃)											
	Z-Nickel	International Nickel	93.7		0.4	4.4				0.3	0.5					0.2

*Rejected

†Lost

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