

REPORT NO. 9

Corrosion of Experimental Aluminum Alloys in High Temperature Water

I. Cohen

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BETTIS PLANT

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Report No. 9Corrosion of Experimental Aluminum
Alloys in High Temperature Water

The work performed by Bettis for the Aluminum Alloy Task Group is reported below. The alloys that were tested are X-2219 (Al-6 w/o Cu), M-388 (Al-1 w/o Ni-0.5 w/o Fe), M-400 (Al-1 w/o Ni-1 w/o Fe), 192263 (Al-1.38 w/o Ni-1.44 Fe), 192264 (Al-2.64 w/o Ni-0.35 w/o Fe-0.35 w/o Cr) and 192265 (Al-4.34 w/o Ni-0.76 w/o Cu-0.38 w/o Fe).

Test Methods

The following corrosion tests were made:

(1) Static autoclave tests at 680°F in both saturated steam and water and at 600°F in water. Deionized water was used and degassed at intervals during the heat-up period. The pH of the water initially and at the end of the test was in the range 6.5 to 7.5. The resistivity of the water was greater than 500,000 ohm-cm for all tests.

(2) Circulating autoclave tests at 680°F in neutral water with and without SbO₃ addition. In these tests the feed water is saturated with H₂ at room temperature and circulated through the autoclaves with Hills-McCanna metering pumps at a maximum flow rate of 1.5 liter/hr. Sampling of the inlet and exit water is made daily for pH measurement. The flow rate remained sensibly constant at 1.3 to 1.5 liter/hr throughout the test periods.

(3) Dynamic loop corrosion test at 600°F in pH 8.5-9.4 water. The velocity was 20 fps in one channel and 1 fps in another. The hydrogen was maintained in the range 80-98 cc/kg with oxygen less than 0.01 ppm. The number of gas analyses made was dependent upon the ability to maintain the required test conditions.

(4) Dynamic loop corrosion test at 650°F in pH 7.0 water with 30 cc/kg of hydrogen. The velocity was maintained at 20 fps and 1 fps in the two loop channels. During the first week of loop operation the hydrogen level increased and degassing of the loop was required to maintain a hydrogen level more nearly that required by the test conditions. Even with degassing the loop, the average H₂ level was 48.9 cc/kg rather than the 25-30 cc/kg requested. The velocities and pH remained constant throughout the test run.

Results and Discussion

A summary of the corrosion data are presented in Tables I to V. All the data included in the tables have been calculated from results obtained by the iodine-methyl alcohol dissolution method and are presented as corrosion rates or metal loss per unit area values. The data are also presented as metal loss per unit area versus time curves where sufficient exposure time has been accumulated. Unless otherwise stated, the alloy identifications X-2219, M-388 and M-400 refer to the respective temps T-6, H-14 and H-14.

680°F Static Water Test

The corrosion results for the 680°F static water test are reported as rates in Table I and the data plotted in Figures 1-3 for the alloys X-2219, M-388 and M-400. The data indicates that alloy M-388 has begun to show an accelerated rate after 196 days of exposure. The total metal weight loss in 196 days was 0.50 g, and in the following 42 day exposure the loss equalled this amount. This is shown by the change of slope in Figure 2 at 196 days of test. Alloy M-400 continues to corrode at a steady rate of 10 mil per year after 224 days exposure. The total metal weight loss for this alloy for this exposure time is 0.52 g. Testing of these alloys will continue to fail.

The new alloys submitted by Alcoa have completed 14 days in 680°F static water. The 14 day data are listed below together with M-388 and M-400 for the same time period for comparison.

<u>Alloy</u>	<u>Composition</u>	<u>Metal Wt. Loss, mg/cm²</u>
192263	Al-1.38 Ni-1.44 Fe	2.44
192264	Al-2.64 Ni-0.35 Fe-0.35 Cr	2.59
192265	Al-4.34 Ni-0.38 Fe-0.76 Cu	2.77
M-388	Al-1.0 Ni-0.5 Fe	5.25
M-400	Al-1.0 Ni-1.0 Fe	4.44

The 14 day data indicates no difference between the new alloys, however, they appear promising when compared with M-388 and M-400.

680°F Water-Steam Phase

The corrosion results for this test are listed as rates in Table II and the data plotted in Figures 2 and 3 for M-388 and M-400, respectively. From Figure 2, it is noted that the M-388 samples in 680°F water and steam are behaving in a similar manner. An accelerated corrosion rate (30 mil per year) for alloy M-388 samples in steam occurs after 140 days exposure. The total corrosion for alloy M-388 is 65 mg/cm² after 210 days, whereas, for the same test time alloy M-400 has a total corrosion of 36 mg/cm² and is corroding at a steady rate of 11.3 mil per year.

600°F Static Water

The corrosion rates for the 600°F static water test are tabulated in Table III, and the data plotted for X-2219, M-388 and M-400 in Figures 1-3. The samples of the three alloys have survived 224 days of exposure. The rates in Table III indicate that the accelerated rate after inflection is continuing for the Al-Ni-Fe alloys with M-400 showing the highest rate with 6.7 mil per year. Alloy X-2219 is apparently corroding at a steady rate of 4.2 mil per year. Annealed samples of M-388 are also apparently corroding at a steady rate of 4.5 mil per year without displaying the inflection point seen for the H-14 and H-18 tempers. The total corrosion for all three alloys after 224 days test ranges from 20 mg/cm² for M-388 to 22 mg/cm² for both M-400 and X-2219. Also, if the average rate from 0 time was used for comparison, all the alloys would be corroding

at a rate around 4.0-4.25 mil per year. There is apparently little difference for the three alloys at this temperature.

The three new alloys are being tested at 600°F. No data are available for this report.

680°F Circulating Neutral Water

The test in 680°F circulating neutral water has completed 126 days exposure. The rates for X-2219, M-388 and M-400 are listed in Table IV, and the data plotted in Figure 4. The start of an accelerated rate for M-388 and M-400 is apparently beginning for these Al-Ni-Fe alloys at 98 and 112 days, respectively. The rates in Table IV, which do not include the points after inflection, indicate a similar behavior for the three alloys. No failures have been found for X-2219 alloy in 119 days exposure.

600°F Dynamic Test-High pH Water

The 600°F dynamic loop test in 20 fps and 1 fps water at pH 9.0 with NH_4OH has completed the assigned 12 week test period. All the data are tabulated in Table V for X-2219 and M-388 alloy samples. The data are plotted in Figures 5 and 6 for M-388 and X-2219, respectively. The results indicate that M-388 samples display a very poor corrosion rate (62.5 mil per year) and X-2219 samples fail by erosion after 5 weeks in the high velocity test section. In the low velocity (1 fps) section, the corrosion rates are 5.18 and 8.36 mil per year for M-388 and X-2219, respectively. A photograph of the eroded X-2219 samples are shown in Figure 7. Note that original as well as replacement samples failed in this manner. Replacement samples displayed a higher total corrosion (mg/cm^2) than original samples for all test times. This test has been discontinued and replaced by a 650°F neutral water test.

650°F Dynamic Test-Neutral Water

The new alloys supplied by Alcoa have completed 28 days exposure to 650°F neutral water together with samples of M-388 and M-400 for comparison. The results to date are listed below:

<u>Alloy</u>	<u>Velocity</u>	<u>H₂</u>	<u>Metal Loss, mg/cm²</u>	
			<u>14 days</u>	<u>28 days</u>
192263	20 fps	30cc/kg	-	22.0
192264	"	"	11.0	15.8
192265	"	"	15.9	26.3
M-388	"	"	11.0	-
M-400	"	"	11.6	13.9
192253	1 fps	30 cc/kg	-	9.26
192264	"	"	4.1	6.2
192265	"	"	9.4	13.6
M-388	"	"	5.5	-
M-400	"	"	4.2	4.1

The results indicate that none of the new alloys improve upon the corrosion resistance of M-400 in 650°F semi-dynamic or dynamic neutral water. Of the new alloys, 192264 appears to be the most promising.

Table ICorrosion Rates of Aluminum Alloys in Static Water at 680°F

<u>Alloy</u>	<u>Temper</u>	<u>Test Time, Days</u>	<u>Rate, mil/year</u>
M-388	H14	14-98	3.27
		98-196	13.19
		196-238	39.06
M-388	H18	14-70	5.40
		70-182	8.55
M-388	Annealed	14-126	6.06
		126-210	25.31
M-400	H14	14-84	3.00
		84-224	10.12
M-400	H18	14-140	5.12
M-400	Annealed	14-140	4.08

Table IICorrosion Rates of Aluminum Alloys in Static 680°F Water-Steam Phase

<u>Alloy</u>	<u>Temper</u>	<u>Test Time, Days</u>	<u>Rate, mil/year</u>
M-388	H14	7-80	4.55
		80-140	12.60
		140-210	30.10
M-400	H14	14-84	5.04
		84-210	11.32

Table IIICorrosion Rates of Aluminum Alloys in Static Water at 600°F

<u>Alloy</u>	<u>Temper</u>	<u>Test Time, Days</u>	<u>Rate, mil/year</u>
M-388	H14	14-98	2.10
		98-224	6.08
M-388	H18	7-77	2.74
		77-182	6.23
M-388	Annealed	7-210	4.53
M-400	H14	14-105	2.02
		105-224	6.77
M-400	H18	7-77	2.66
		77-182	6.70
M-400	Annealed	14-133	1.82
		133-217	8.56
X-2219	T-6	14-224	4.19

Table IVCorrosion Rates of Aluminum Alloys in 680°F Circulating Neutral Water

<u>Alloy</u>	<u>Temper</u>	<u>Test Time, Days</u>	<u>Rate, mil/year</u>
X-2219	T6	14-98	4.40
M-388	H14	14-98	5.60
M-400	H14	14-112	3.82

Table V

Corrosion Results of Statistically Designed Dynamic Loop Test in 600°F WaterTest Conditions: pH=9.0 (NH₄OH); H₂=100 cc/kg; O₂->0.1 ppmMetal Weight Loss in mg/cm²

<u>Alloy</u>	<u>Velocity</u>	<u>Lot No.</u>	<u>1</u>	<u>3*</u>	<u>5</u>	<u>7*</u>	<u>9</u>	<u>11*</u>	<u>12</u>	
M-388	20 fps	1	6.07	33.96	28.39	77.18	70.79	86.11	97.52	
		2	6.64	40.89	25.45	74.13	77.46	99.07	113.20	
		1								89.52
		2								91.93
X-2219	20 fps	1	7.67	32.67	28.40	(Erosion failures, see Fig. 7)				
		2	9.82	36.22	24.06					
M-388	1 fps	1	2.34	9.15	8.02	14.44	10.14	11.40	8.15	
		2	2.52	11.41	4.40	9.83	6.56	4.86	12.58	
		1								7.53
		2								11.89
X-2219	1 fps	1	3.17	7.70	6.12	15.12	9.51	12.29	15.02	
		2	5.04	8.18	9.48	20.95	9.97	18.75	22.52	
		1								14.98
		2								14.40

* Values for replacement samples

8

Corrosion of Alloy X-2219 in High Temperature Water and Steam

LS7
&

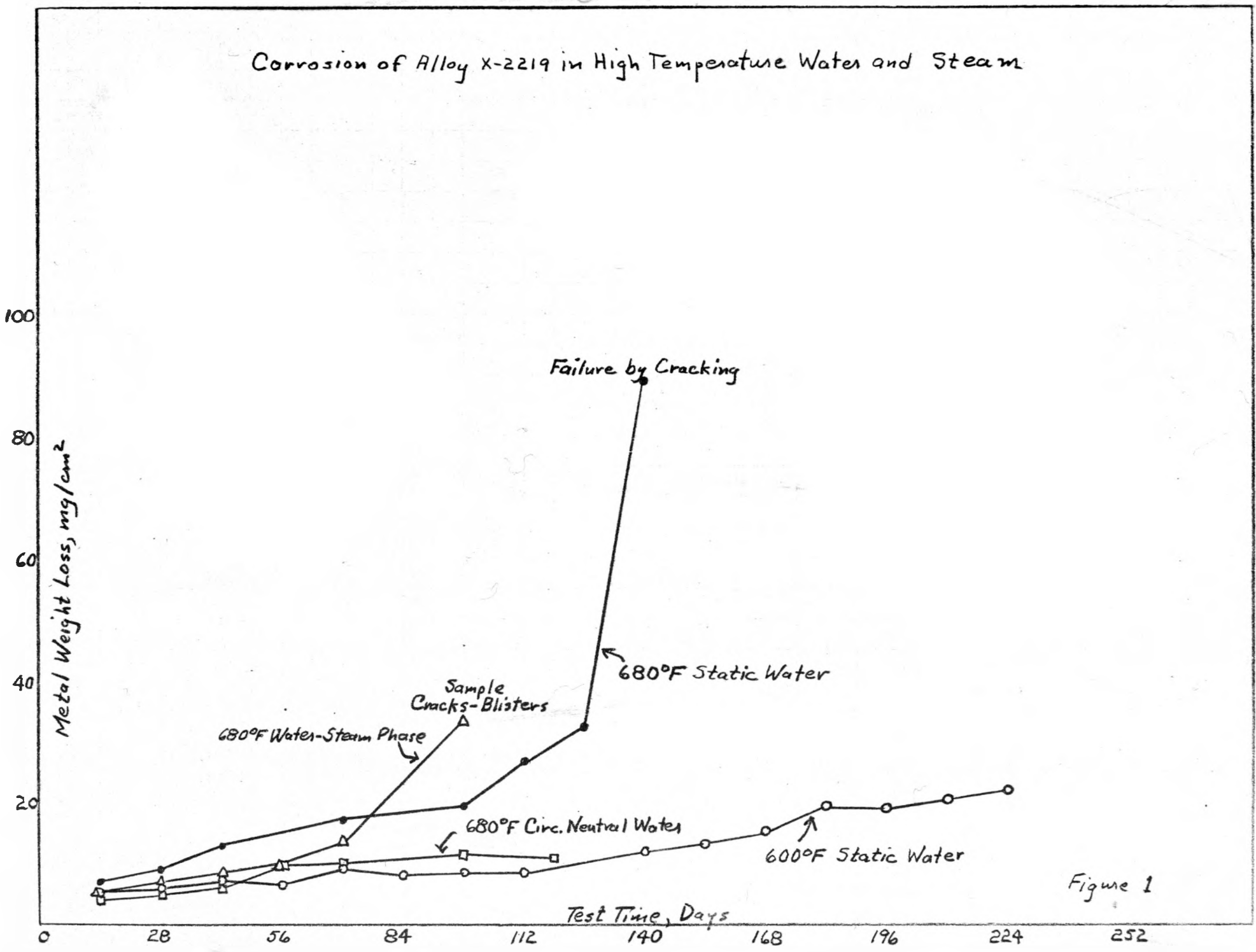


Figure 1

Corrosion of Alloy M388-H14 in High Temperature Water and Steam

657-257

Metal Weight Loss, mg/cm²

100

80

60

40

20

0

28

56

84

112

140

168

196

224

252

Test Time, Days

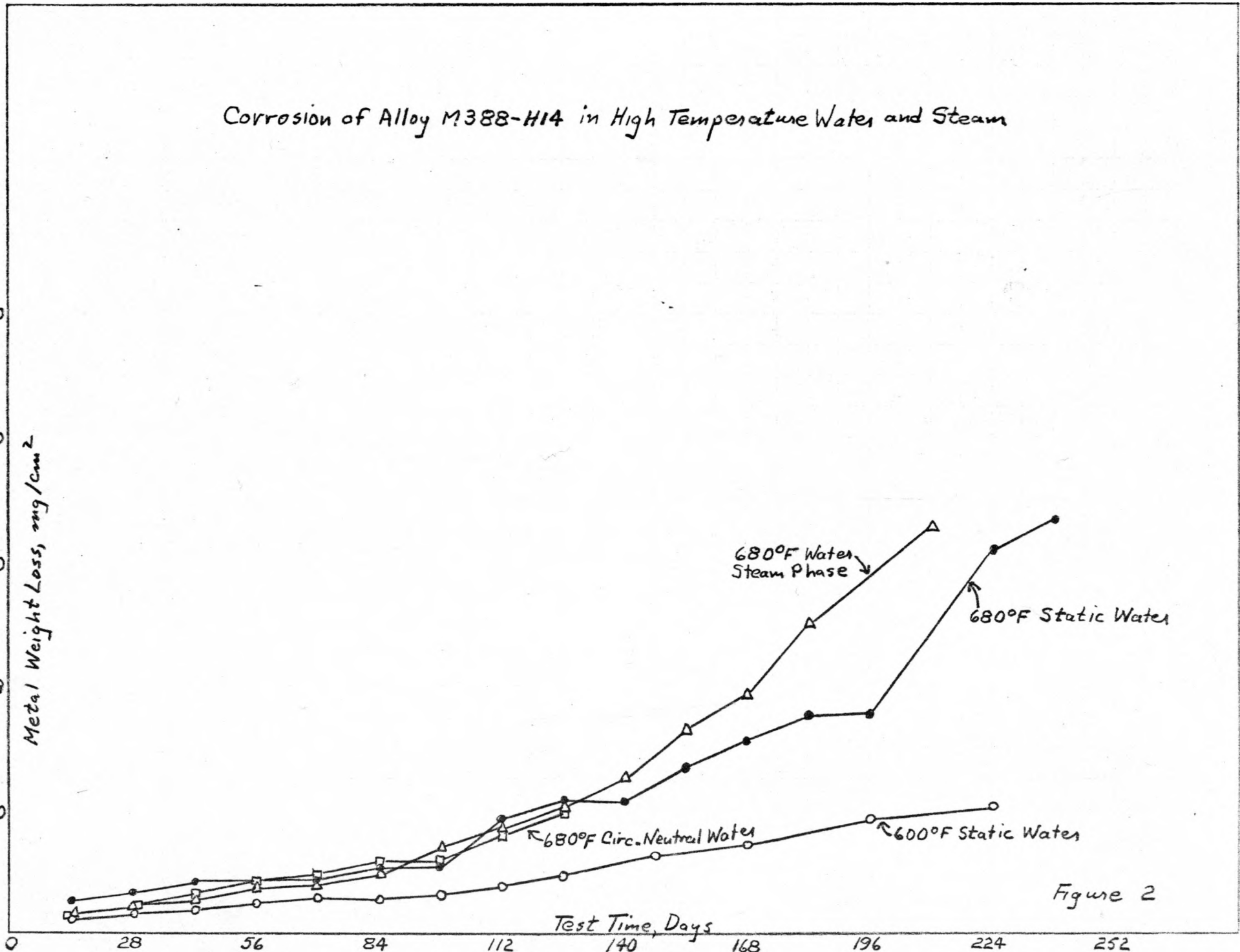
680°F Water
Steam Phase

680°F Static Water

680°F Circ. Neutral Water

600°F Static Water

Figure 2



10

Corrosion of Alloy M400-H14 in High Temperature Water and Steam

01-259

Metal Weight Loss, mg/cm²

Test Time, Days

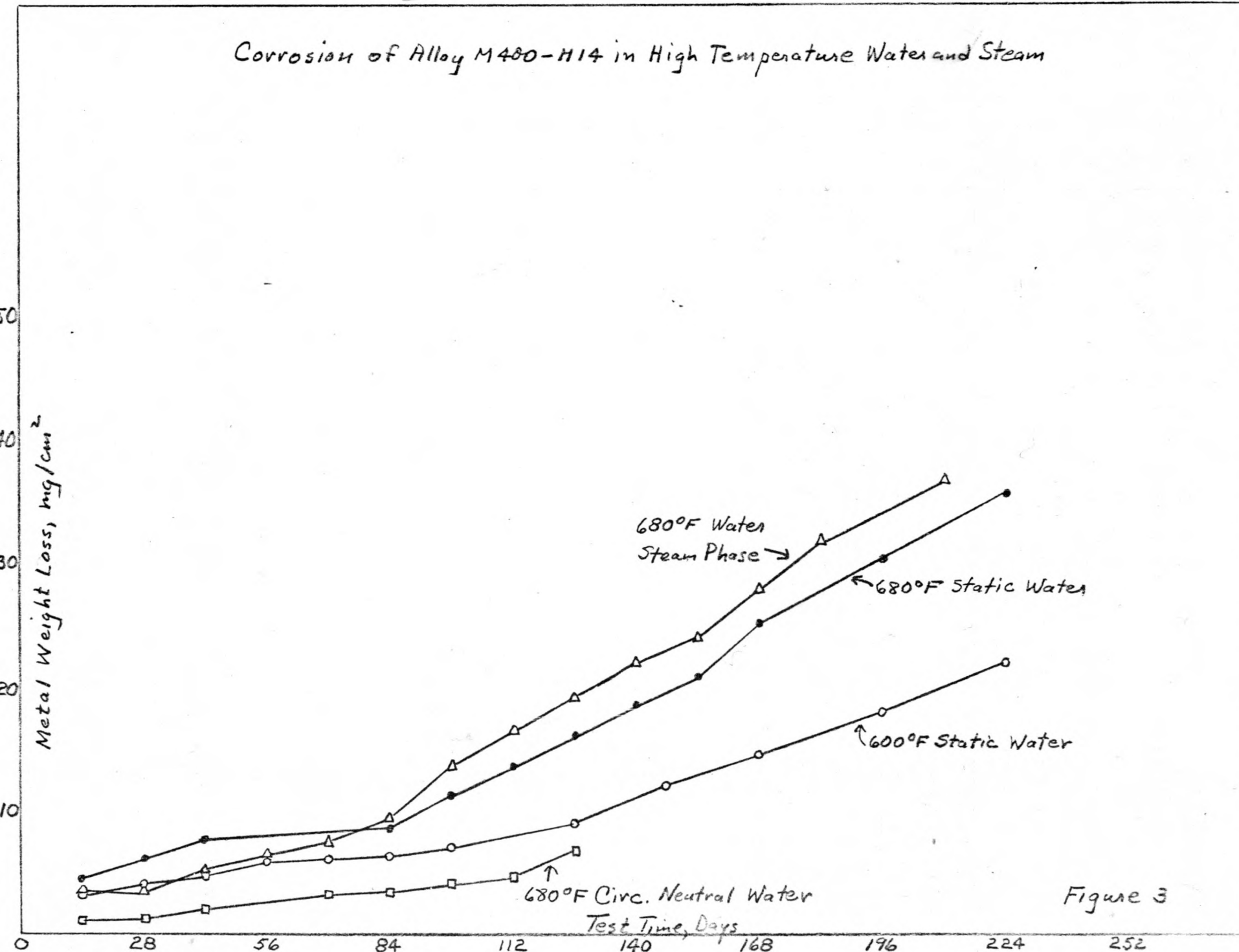


Figure 3

Corrosion of Aluminum Alloys in 680°F Circulating Neutral Water

Key Alloy
X X2219-T6
O M38B-H14
Δ M400-H14

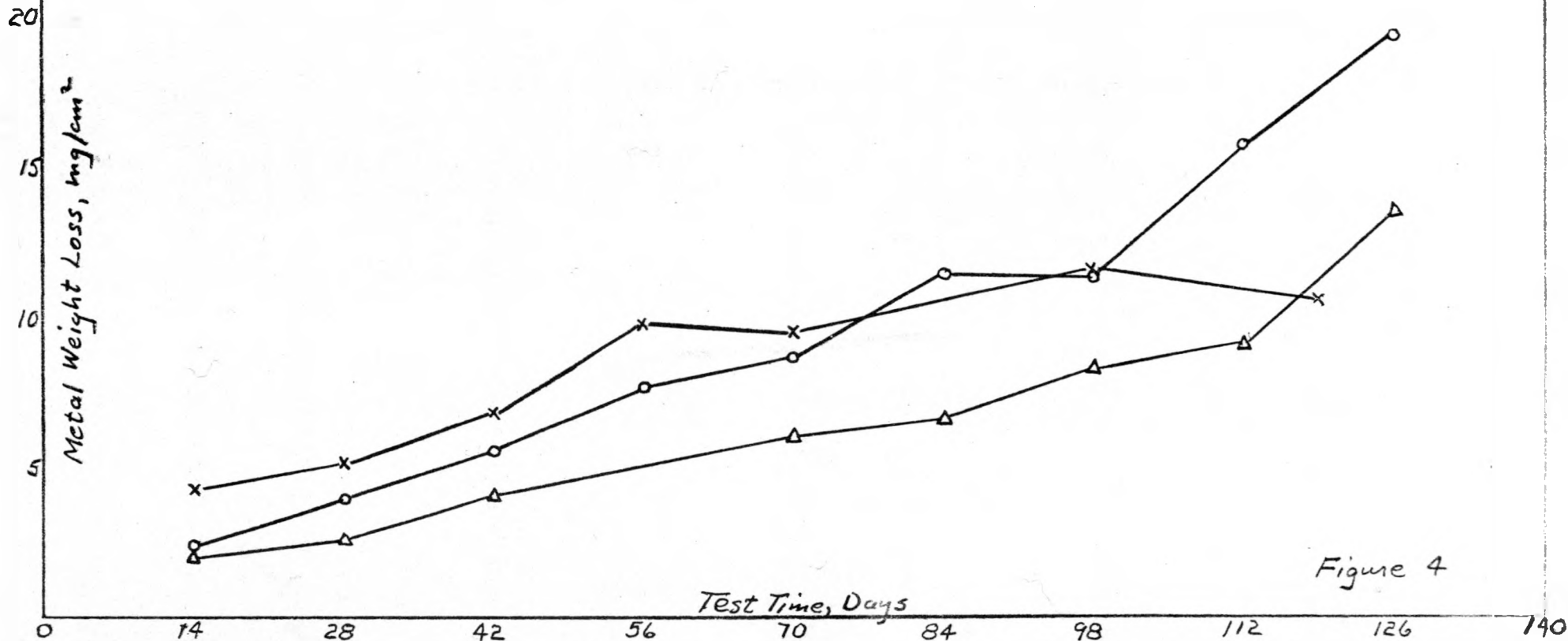


Figure 4

11-659

Corrosion of M-388-H14 in 600°F Dynamic Water
 pH=9.0 with NH_4OH $H_2=100cc/kg$

657-12

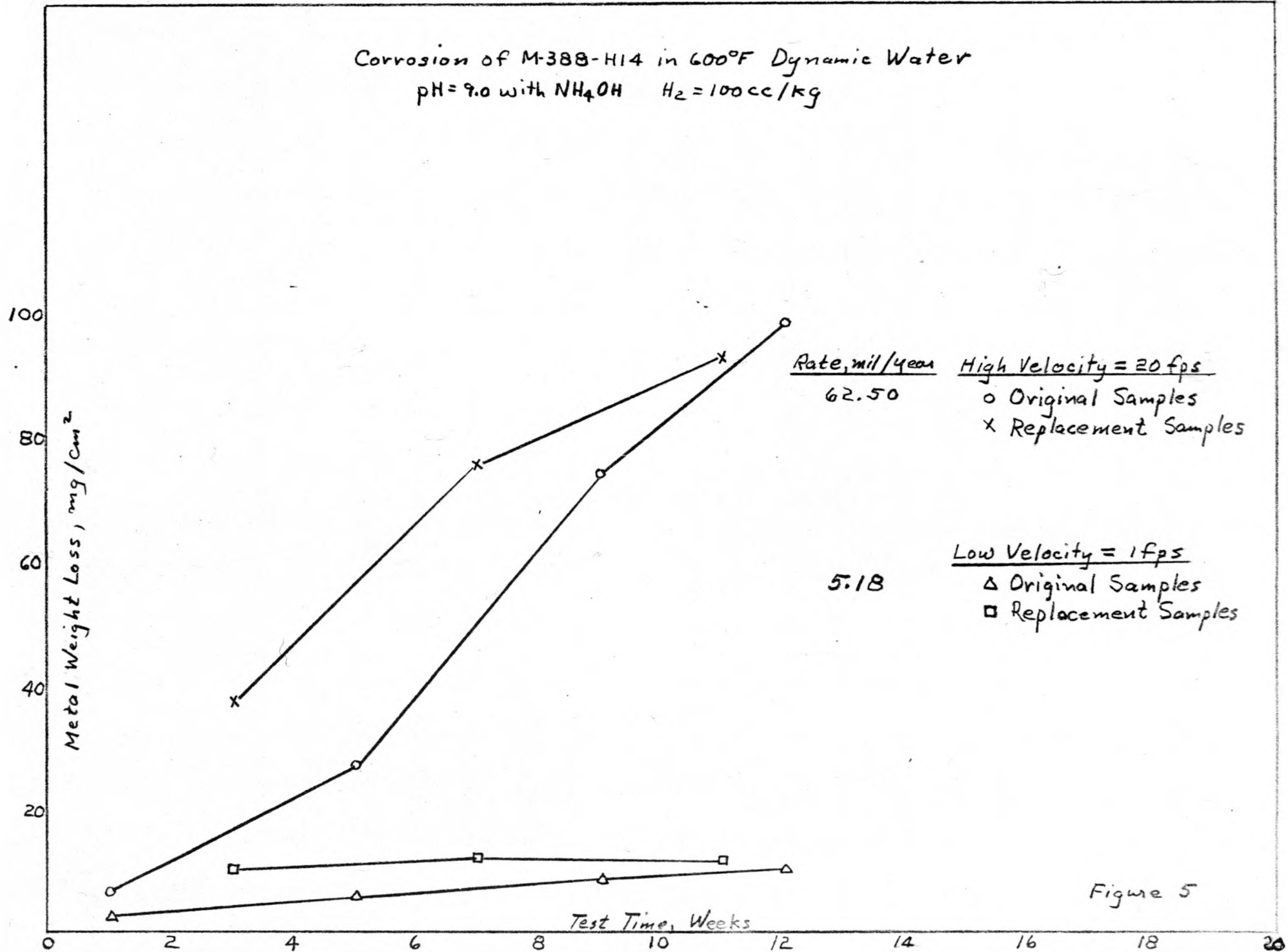


Figure 5

Corrosion of X 2219-T6 in 600°F Dynamic Water
 pH = 9.0 with NH_4OH
 $\text{H}_2 = 100\text{cc/Kg}$

657-13

Metal Weight Loss, mg/cm²

High Velocity = 20 fps

○ Original Samples

x Replacement Samples

Note: Samples which failed by erosion are not plotted
 (see Figure 7)

Rate

Low Velocity = 1 fps

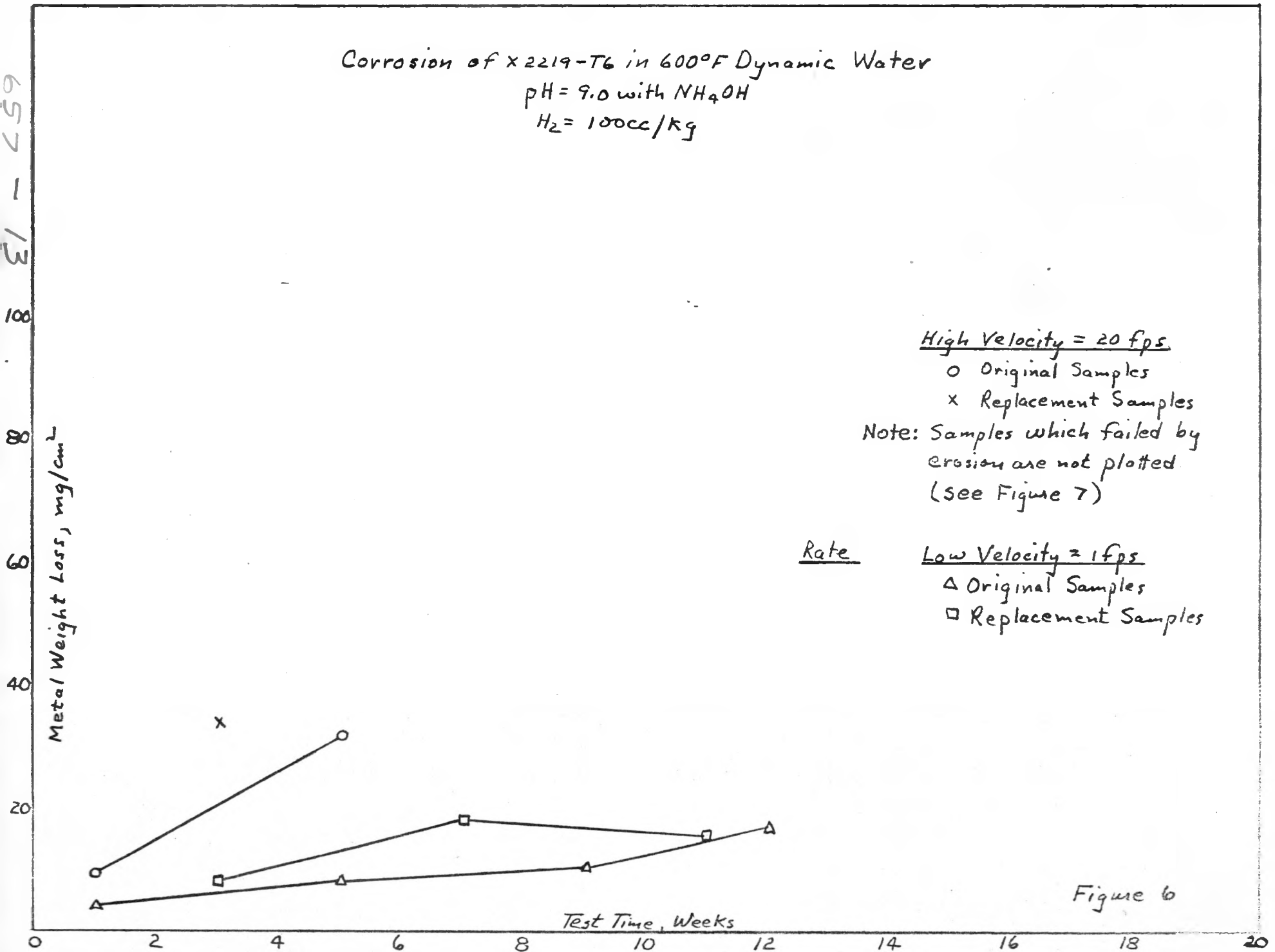
△ Original Samples

□ Replacement Samples

0 2 4 6 8 10 12 14 16 18 20

Test Time, Weeks

Figure 6



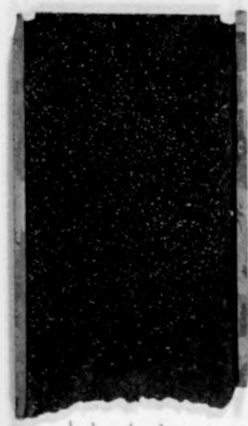
LOOP SAMPLES
600°F - 20FT/SEC. - PH. 9 - H₂-100cc/LITER

1344 HR.

1512-HR.

672-HR.

1512-HR



H-1A

H-5

H-16A

H-18

X-2219-T6 - 187438

1344-HR.

1512-HR.

1512-HR.



H-2A

H-7

H-17

X-2219-T6 - 187439



Figure 7

657-14

14