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1954

THE CORROSION OF 356 ALUMINUM IN SIMULATED COOLING WATER FOR THE PROPOSED MATERIALS TESTING REACTOR

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REACTOR TECHNOLOGY DIVISION

THE CORROSION OF 356 ALUMINUM IN SIMULATED COOLING WATER FOR THE PROPOSED MATERIALS TESTING REACTOR

James L. English

Date Issued JUL 20 1950

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1.0 INTRODUCTION

This report on the corrosion of 356 aluminum is issued by the Corrosion Group of the Reactor Technology Division, Oak Ridge National Laboratory, as Part II of a series of reports concerned with corrosion studies for the proposed Materials Testing Reactor. The first report of this series was issued as Part I, entitled "An Interim Report on the Corrosion of Beryllium," on March 18, 1949, (ORNL-298). The first report described in detail the origin and history of the corrosion program for the Materials Testing Reactor, the establishment of the corrosion testing conditions, the corrosion test methods and equipment used, and the methods for evaluation of corrosion damage. No attempt is made to repeat this information in the present report on 356 aluminum.

This report is not intended as a theoretical presentation on the corrosion of 356 aluminum, but deals entirely with the engineering corrosion problems that are to be found in the operation of the proposed Materials Testing Reactor.

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2.0 ABSTRACT

A report is presented on the corrosion of 356 T-7 aluminum in simulated cooling water for the proposed Materials Testing Reactor. Stagnant and dynamic corrosion tests were conducted in demineralized water containing small amounts of hydrogen peroxide at a pH range of 5.5-6.5 and a temperature of 85°C. Corrosion behavior of the uncoupled alloy was investigated as well as its galvanic corrosion behavior with 2S aluminum, 43 aluminum, extruded beryllium, and 347 stainless steel. Sodium chromate and sodium dichromate were tested as possible corrosion inhibitors.

The corrosion characteristics of 356 aluminum are greatly influenced by oxygen concentrations, pH, and contact with dissimilar metals. Heat treatment of the alloy effected the corrosion resistance slightly; cast aluminum showed a slightly superior corrosion resistance to the heat treated alloy. Corrosion attack on the alloy at 90°C was of similar magnitude as attack at 30°C; maximum corrosion attack occurred at 50°C. Stagnant vs. dynamic test results indicated that pitting intensity was reduced under dynamic conditions but the general corrosion rate was increased. Corrosion attack generally increased as the hydrogen peroxide concentration increased from 0.0005M to 0.005M. Galvanic corrosion attack on the alloy was most severe when coupled to 347 stainless steel. Sodium chromate in concentrations of 10 ppm. was effective for reducing corrosion attack. A general observation of all test results indicated that an incubation period of 500-700 hours was required for the formation of the protective hydrated aluminum oxide film.

The average overall stagnant corrosion rate for 356 aluminum in deaerated water, 0.0005M and 0.005M hydrogen peroxide solutions for 1008 hours was 0.007 mil/month; the average dynamic corrosion rate for similar conditions was 0.067 mil/month. In deaerated water, the presence of 10 ppm. of sodium chromate resulted in negligible corrosion rates; in waters containing 0.0005M and 0.005M hydrogen peroxide concentrations, the average corrosion rate was 0.020 mil/month with almost complete elimination of pitting attack.

Galvanic corrosion of 356 aluminum in contact with 2S aluminum, 43 aluminum, extruded beryllium, and 347 stainless steel in deaerated water, 0.0005M hydrogen peroxide, and 0.005M hydrogen peroxide solutions averaged 0.013, 0.010, 0.025, and 0.355 mil/month for 1008 hours exposure, respectively. With 5-10 ppm. of sodium chromate in the test solutions, these corrosion rates were reduced to 0.007 mil/month in contact with 2S aluminum; 0.001 mil/month in contact with extruded beryllium, and 0.007 mil/month in contact with 347 stainless steel.

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2.0 ABSTRACT (CONT'D.)

The maximum pit depth encountered on stagnant 356 aluminum test specimens was 16.4 mils in 1008 hours; for dynamic test conditions, the maximum pit depth encountered was 8.0 mils for the same time. The presence of 5-10 ppm. of sodium chromate was very effective for reducing the magnitude of these pit depths as well as reducing pit frequencies.

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3.0 STATEMENT OF THE PROBLEM

The decision to use 356 aluminum casting alloy as a construction material for the fuel rod end boxes and the grid structures in the Materials Testing Reactor created the need for corrosion data on this alloy in the reactor cooling water. An investigation was undertaken to determine its corrosion resistance when exposed to simulated cooling water containing small concentrations of hydrogen peroxide at 85°C.

One important phase of this study dealt with the galvanic corrosion behavior of 356 aluminum in contact with dissimilar metals and alloys. Design features of the reactor necessitated the contact of the aluminum with metals such as 2S aluminum and 347 stainless steel. A junction with 2S aluminum exists where the end boxes join with the active fuel rod assemblies. Another area of dissimilar metal contact exists where a 347 stainless steel positioning ring, used for spacing and positioning the assemblies in the upper grid, contacts the 356 aluminum end boxes.

One other important phase in the corrosion investigation was concerned with the nature of the corrosion products on the aluminum at junctions with dissimilar metals. The formation of voluminous corrosion products is undesirable inasmuch as they present the possible hazard of accumulating at stagnant areas in the narrow cooling channels with resulting blockage of water flow. Such a restriction could possibly cause overheating or localized hot spots during reactor operation. It is also undesirable to have bulky corrosion products present in the cooling water for the reason that they may form or collect in an interfacial area, i.e. where the end boxes slide into the grid, and create a tenacious bond which would interfere with easy removal of the fuel rods from the reactor chamber.

These, and numerous other problems, were the basic reasons for the decision to proceed with a corrosion investigation on 356 aluminum.

4.0 CORROSION TEST CONDITIONS

The probable condition and specifications for the cooling water in the Materials Testing Reactor is presented in detail in Section IV of ORNL-298, "An Interim Report on the Corrosion of Beryllium in Simulated Reactor Water." For review purposes, a brief resume of these conditions is included in Table 1.

4.0 CORROSION TEST CONDITIONS (CONT'D.)

TABLE I

PROBABLE CONDITION OF REACTOR COOLING WATER

Medium	Deaerated, demineralized water having a specific resistance of 3×10^5 ohms/cm. minimum at 25°C		
Water Specifications	Total solids	8.0	ppm
	Fe	0.05	"
	Al	0.05	"
	Ca	0.5	"
	Mg	0.5	"
	Na	1.0	"
	CO_2	2.0	"
	SiO_2	5.0	"
	Cl	0.2	" max.
	SO_4	5.0	"
	Cu	0.04	"
	B	0.0	"
Water pH	5.5-6.5		
Water Velocity	20-30 feet/second		
Water Temperature	38-46°C		
Hydrogen Peroxide	0.0005M-0.005M		

4.0 CORROSION TEST CONDITIONS (CONT'D)

The exact concentration of hydrogen peroxide formed in the cooling water by beta and gamma radiations, or by bombardment with alpha particles or recoil protons, is difficult to predict. The equilibrium concentration depends upon many factors; radiation intensity, dissolved oxygen content in the entry water, water temperature, water pH, and the presence of various metallic ions such as iron, chromium, copper, etc. With the aid of a limited amount of information, the range of 0.0005M-0.005M was selected to include any formation and concentration of hydrogen peroxide that could occur under the expected conditions of operation.

5.0 CORROSION TEST MATERIALS

5.1 Types of Materials

The 356 aluminum alloy used for the corrosion tests was obtained from the Aluminum Company of America in the form of cast bars and billets. The billets were remelted and cast into 1 1/4 inches diameter bars, 12 inches in length. The bars were then subjected to a precipitation hardening heat treatment.

The specimens were machined from the cast and heat treated bars into discs, 1/4 inch thick by 1 1/8 inches diameter. The samples were polished on No. 80 and 120 emery paper, respectively, and then defilmed in 2% hydrofluoric acid solution for 30 seconds at room temperature. The specimens were rinsed thoroughly in cold, running water, followed by rinsing in acetone and alcohol. The final operations consisted of drying at 120°C for 20-30 minutes and weighing. Surface areas were determined after the final polishing operation.

The 2S aluminum was obtained from the Aluminum Company of America as 1 1/4 in. diameter bars. Extruded beryllium was procured from Massachusetts Institute of Technology, and the 347 stainless steel was obtained from Material Stores at Oak Ridge National Laboratory. The size of these corrosion test specimens was similar to that of the 356 aluminum samples. All specimens had a 1/4 inch hole drilled through the center for means of support by glass hooks in the test media.

After exposure, the specimens were defilmed in various chemical solutions to remove adherent films and corrosion products. Aluminum alloys were defilmed in a mixture of 2% chromic acid and 5% phosphoric acid for 20 minutes at 50°C. Extruded beryllium was defilmed in cold, 25% nitric acid for 20 minutes. Type 347 stainless steel was defilmed

5.1 Types of Materials (Cont'd)

in 20% hydrochloric acid solution containing 5% Rodine 60 inhibitor for 5-10 minutes at room temperature. The weight losses of the base metals incurred by these treatments are shown in Table II.

TABLE II

WEIGHT LOSS ON TEST MATERIALS BY CHEMICAL DEFILMING TREATMENTS

Material	Wt. Loss, mg/cm^2
43 Aluminum	0.012
356 Aluminum	0.016
347 Stainless Steel	0.020
Extruded Beryllium	0.012

5.2 Chemical Compositions of Test Materials

Nominal chemical analyses of the test materials used in the corrosion investigation are shown in Table III.

TABLE III

NOMINAL CHEMICAL ANALYSES, IN PERCENT, OF CORROSION TEST MATERIALS

Material	Fe	Cu	Mn	Zn	Si	Mg	Ni	Cr	C	Al
356 Al	0.25	0.09	0.10	0.10	7.46	0.37	-	-	-	bal
2S	0.54	0.15	0.10	0.10	0.25	-	-	-	-	bal
43 Al	0.16	0.08	0.10	-	5.67	0.05	-	-	-	bal
347 S.S.*	bal.	-	1.44	-	0.75	-	10.50	18.10	0.08	-
Beryllium	0.05	0.01	0.002	0.005	0.002	0.006	0.001	0.01	0.02	0.03

* Cb content approximately 8 x C

5.3 Metallurgical Data

As mentioned previously, the 356 aluminum alloy was tested in cast and heat treated conditions. The heat treatment given the material is commercially designated as "T-7" and consisted of a solution heat treatment followed by a stabilizing treatment. The complete heating cycle was:

a) heat for 12 hours at 538°C
b) quench in boiling water
c) heat for 9 hours at 227°C

Prior to use, the 2S aluminum was annealed at 245°C in a normal atmosphere. The 43 aluminum casting alloy was tested in a cast condition. Beryllium and 347 stainless steel were tested in the condition in which they were received.

The average hardnesses of the test materials are included in Table IV. Physical properties of 356T-7 aluminum are shown in Table V.

TABLE IV

AVERAGE HARDNESS VALUES FOR CORROSION TEST MATERIALS

Material	Condition	Hardness, R_{15T}	Equivalent Hardness, Brinell*
356 Aluminum	Cast	73.0	73
356 Aluminum	T-7	76.0	80
2S Aluminum	Annealed	-	24
43 Aluminum	Cast	-	45
Extruded Beryllium	As Received	84.5	116
347 Stainless Steel	As Received	86.0	126

* 10 mm. diameter ball and 500 kg. load

5.3 Metallurgical Data (Cont'd)

TABLE V

AVERAGE PHYSICAL PROPERTIES OF 356 T-7 ALUMINUM ALLOY[1]

Tensile strength, psi.	34,000
Tensile yield strength, psi.	30,000
Elongation, percent in 2 in.	2
Compressive yield strength, psi.	30,000
Brinell Hardness, 500 kg. load	75
Shearing strength, psi	18,000
Specific gravity	2.62
Weight, lb/cu ft	164.20
Thermal conductivity, cal./sec/cm^2/cm thickness/°C	0.37
Electrical conductivity, percent of Inter. Annealed Copper Std.	40

This aluminum-silicon alloy has excellent casting qualities and can be used successfully for the production of large, thin-walled castings of intricate design. The castings will withstand fairly high fluid pressures without leaking.

[1] Alcoa Aluminum and Its Alloys, Hdbk. published by the Aluminum Company of America, Pittsburgh, Pa., 1947, pages 89-95.

6.0 CORROSION TEST METHODS

6.1 Test Equipment

The test apparatus and equipment for stagnant and dynamic types of corrosion tests is fully described in ORNL 298, pages 17-20. A similar type of apparatus was used in the present study for both stagnant and dynamic tests. The average peripheral velocity of the dynamic specimens was 6-8 feet/second.

A volume of 4 liters of test solution for each test was contained in a 5 liter, cylindrical Pyrex flask. The solutions were heated by means of infra red lamps with temperature control maintained within $\pm$ 0.5°C by means of a mercury thermoregulator and an electrical relay system. Hydrogen peroxide solution was added to the test solutions from burettes attached to each flask. A photograph of the test apparatus is shown in Figure 1.

6.2 Test Solutions

Demineralized water was used as the test medium. An average demineralized water analysis over the period of the tests is shown in Table VI.

Hydrogen peroxide concentrations were maintained in the test solutions by the addition of 4% peroxide prepared from a 30% solution of concentrated hydrogen peroxide. Daily peroxide determinations were made by a standard potassium permanganate titration. Adjustments were made as required and regular peroxide additions were made every 4 hours during the course of the test.

The pH of the test solutions was determined and adjusted daily. A complete description of the methods of solution control and maintenance is found in ORNL-298, pages 20-26.

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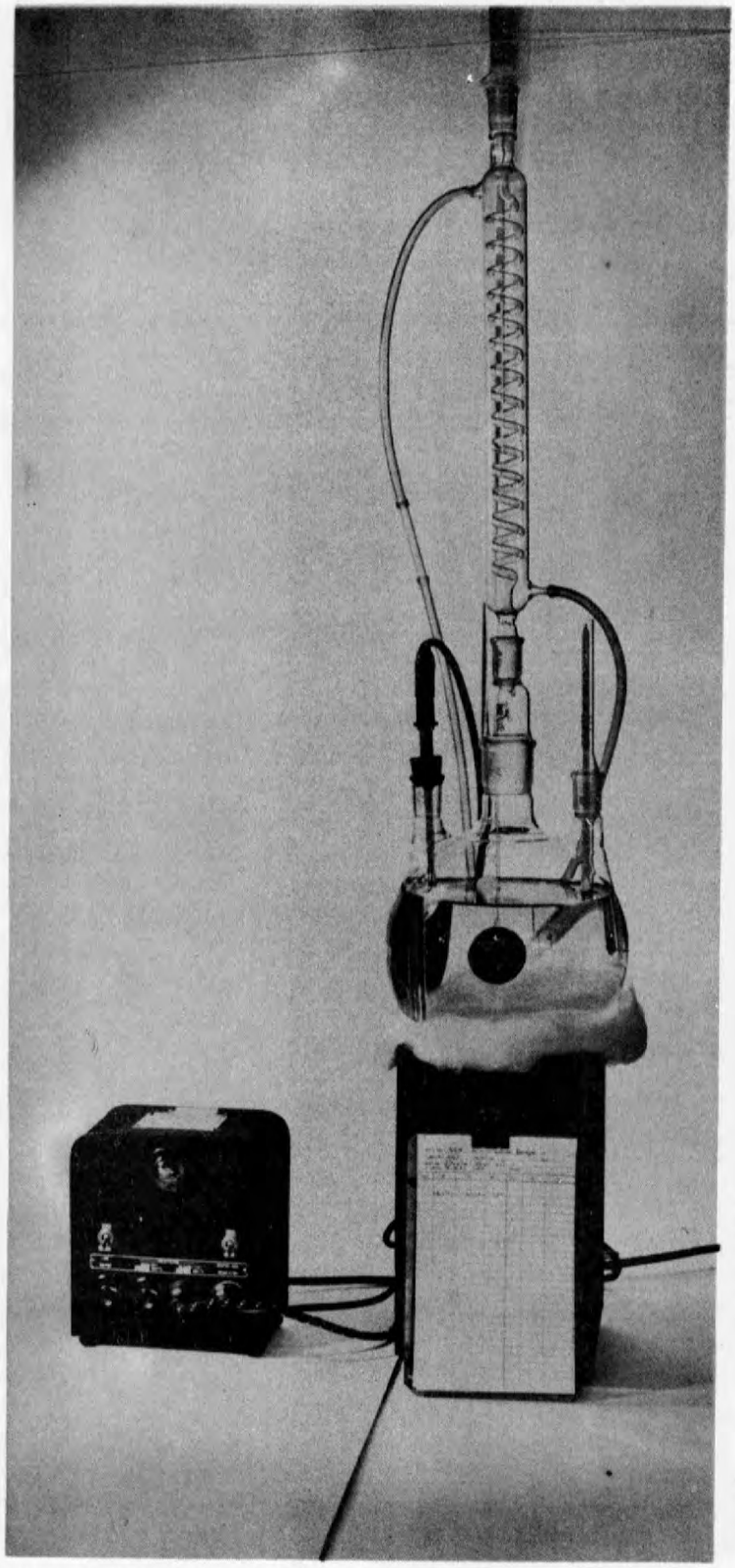

FIG. 1 PHOTOGRAPH OF TYPICAL CORROSION TEST UNIT

6.2 Test Solutions (Cont'd)

TABLE VI

AN AVERAGE ANALYSIS OF DEMINERALIZED WATER USED FOR CORROSION SOLUTIONS

Specific resistance	5.9×10^5 ohms/cm. at 25°C
Dissolved CO_2	2.1 ppm
Dissolved solids	8.3 "
pH	5.5
Iron	0.02 ppm
Aluminum	<0.01 "
Copper	<0.02 "
Nickel	<0.05 "
Chromium	<0.05 "
Calcium	0.12 "
Magnesium	0.16 "
Sodium	1.30 "
Sulfate	5.00 "
Chloride	0.30 "
Carbonate	2.10 "
Bicarbonate	4.20 "

7.0 STAGNANT AND DYNAMIC CORROSION DATA

7.1 Atmospheric Corrosion

No corrosion tests were conducted with 356 aluminum exposed to normal atmospheres since much data have already been accumulated and reported on this subject. It is well known that the aluminum alloys are highly resistant to warm, humid conditions where there is appreciable moisture condensation present. However, it has been found that if impurities are present in such an atmosphere, localized corrosion attack is very apt to occur on the alloys.

The excellent corrosion resistance of aluminum alloys in normal atmospheres is attributed to the fact that the aluminum reacts with the oxygen in the air to form a thin, tightly adherent, almost invisible film of aluminum oxide. This oxide has a higher specific volume than the metal from which it was formed, and for this reason, it is believed that the film forms under lateral compression. If temperatures are not too high, the metal will be entirely covered and protection may be complete when the film is a few molecules in thickness. This film starts to form as soon as a fresh metallic surface is exposed to the air, and in moist air, this film may grow for days and even months. The natural film has a thickness varying from 10-100 Angstrom units, and is generally thought to be amorphous in character.

7.1 Atmospheric Corrosion (Cont'd)

The aluminum oxide film has an appreciable absorptive capacity, especially for water vapor. Water or water vapor plays an important part in the continued growth of the film. Films formed by simple exposure to air are usually inadequate for protection against corrosion by fresh and natural waters, so that a new film is formed on immersion in these waters. The formation of this additional layer involves the conversion of metallic aluminum to a hydrated alumina. The subsequent corrosion attack on the base metal is usually negligible during this transition.

The corrosion product formed on aluminum and its alloys exposed to water is the beta-trihydrate alumina having the formula $\beta.Al_2O_3.3H_2O$. When the water temperature is maintained between 70-100°C, the alpha-monohydrate alumina, $\alpha.Al_2O_3.H_2O$, tends to form.[1]

7.2 Demineralized Water Corrosion

The corrosion behavior of 356 aluminum was first studied in demineralized water at 85°C. Stagnant and dynamic corrosion tests were conducted and the test results are included in Table VII and VIII. It should be mentioned that all test data included in the following tables in this report are for the heat treated or T-7 form of 356 aluminum, unless otherwise stated.

Corrosion attack was more pronounced on the dynamic test specimens in all cases for exposures in deaerated, demineralized water. The initial corrosion rate on these specimens was considerably higher than on the stagnant specimens, indicating that the formation of the protective film was much slower when the specimens were rotated in the solutions. This effect may be attributed to the removal of the initial oxide film by the wearing action of the water during rotation. This wearing action is further substantiated by an observation of the weight gains on the stagnant and dynamic specimens during the first 168 hours of exposure. A gain in weight of 9.8 mg/dm^2 was reported for the former, while a gain of only 4.93 mg/dm^2 was observed on the dynamic specimen. In all tests, weight gains were reported for stagnant and dynamic test specimens as they were removed from the test solutions. The weight losses, after defilming, are plotted in Figure 2 as a function of exposure time. The appearance of the curves for both types of test was similar. Only partial protection by the oxide film was indicated up to 504 hours exposure. The following 336 hours showed diminishing corrosion losses. At the end of a total of 840 hours exposure, an apparent film breakdown occurred in both stagnant and dynamic tests with resulting increased corrosion attack.

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[1] Composition and Properties of the Natural Oxide Film on Aluminum, F. Keller and J. D. Edwards, Metal Progress, August, 1948.

[redacted]

TABLE VII

THE CORROSION OF 356 ALUMINUM IN STAGNANT, DEAERATED WATER AT 85°C

Solution pH	Exposure hr.	Area, cm^2	Pits per cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
5.9	168	14.14	0.1	1.8	4	9.80	8.48	0.054
5.9	168	14.14	0.5	7.4	40	7.18	11.31	0.071
6.2	336	14.14	neg.	neg.	neg.	12.72	12.02	0.038
6.2	336	14.14	neg.	neg.	neg.	10.60	10.40	0.035
6.2	504	14.14	0.4	2.0	24	13.42	15.55	0.015
6.2	504	14.14	0.3	5.2	20	11.32	7.07	0.006
6.1	672	14.14	0.1	1.4	10	8.48	3.53	0.006
6.1	672	14.14	0.1	4.0	40	10.60	7.07	0.011
6.0	840	14.14	neg.	neg.	neg.	12.00	5.65	0.007
6.0	840	14.14	neg.	neg.	neg.	12.72	7.00	0.009
6.2	1008	14.14	neg.	neg.	neg.	11.30	5.65	0.006
6.2	1008	14.14	1.6	13.7	60	13.42	12.01	0.013

Removed Wt. Gain: weight gain of sample as removed from test solution.

Defilmed Wt. Loss: the weight loss of the specimen after defilming, corrected for base metal loss by the defilming treatment.

[redacted]

[redacted]

TABLE VIII

THE DYNAMIC CORROSION OF 356 ALUMINUM IN DEAERATED WATER AT 85°C

Solution pH	Exposure hr.	Area, cm^2	Pits per Cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
6.2	168	14.2	0.1	6.0	60	4.93	21.85	0.138
6.2	336	14.0	3.1	1.6	40	13.58	22.15	0.070
6.2	504	14.0	2.3	7.6	40	11.42	22.90	0.048
6.2	672	14.2	3.2	4.0	28	12.70	18.33	0.029
6.2	840	14.2	0.5	8.0	80	14.10	17.60	0.022
6.2	1008	14.1	0.8	6.4	20	12.06	30.54	0.032

Note: The average specimen velocity was 6-8 feet/second.

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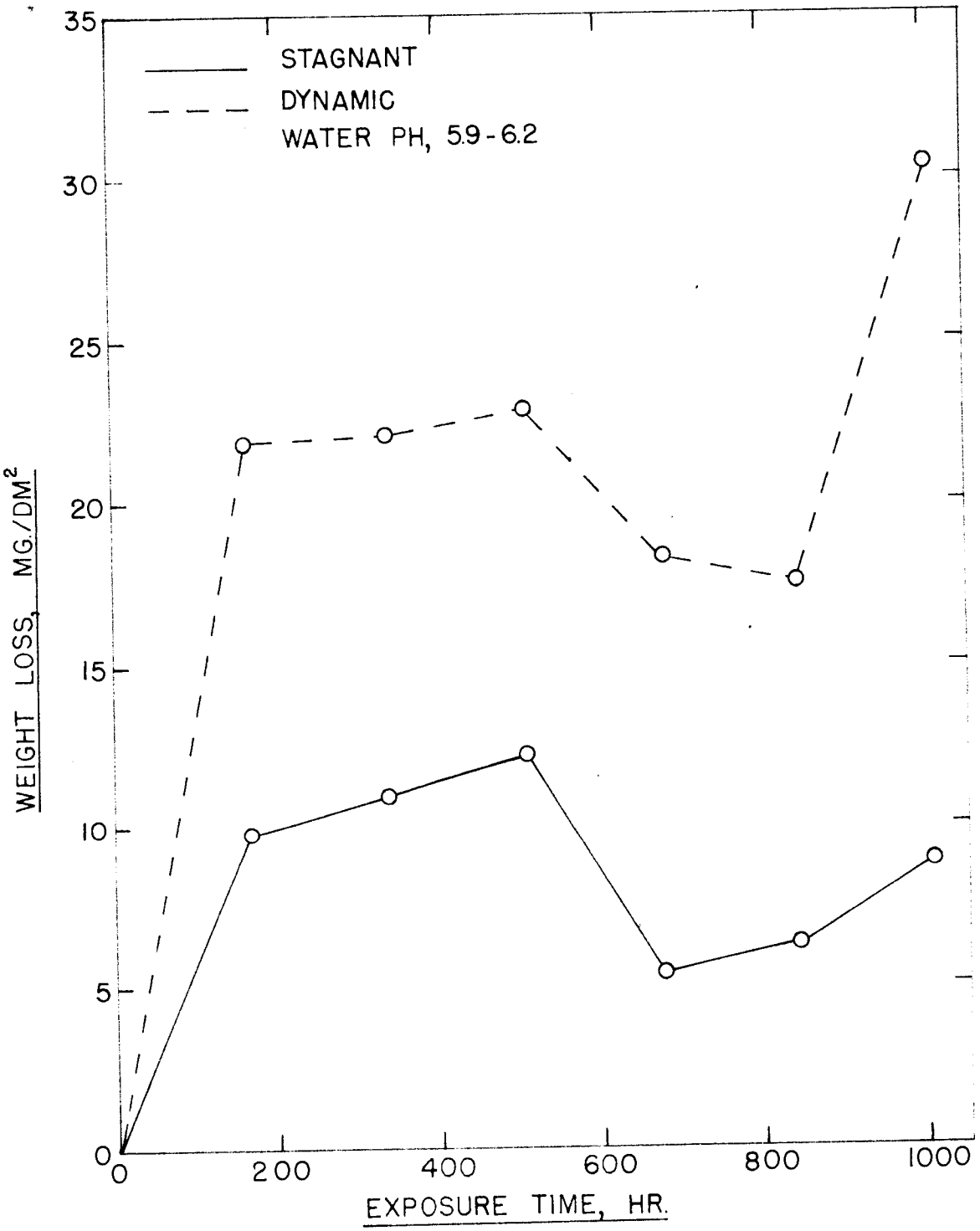

FIG. 2 STAGNANT AND DYNAMIC CORROSION OF 356 ALUMINUM IN DEMINERALIZED WATER AT 85°C

7.2 Demineralized Water Corrosion (Cont'd)

A greater frequency of pits appeared on the dynamic specimens. A maximum pit count/sq cm of 3.2 pits was reported as compared to a maximum count of 1.6 pits/sq cm on the stagnant specimens. The deepest pit, 13.7 mils, was observed on a stagnant specimen exposed for 1008 hours. The average pit depth on stagnant specimens was 2.9 mils; the average depth on dynamic specimens was 5.6 mils. Figure 3 shows the frequency of pitting attack.

Stagnant corrosion tests were conducted in which demineralized water test solutions were constantly aerated by means of a stream of air passed into the solutions. The effect of oxygen on the corrosion of 356 aluminum was studied by these tests. Duplicate test specimens were used and the water pH was maintained at 6.1-6.2. The water temperature was 85°C. The tests were operated for 1008 hours. Average test results are shown in Table XIX in comparison with deaerated corrosion test results.

TABLE XIX

THE EFFECT OF AERATION ON THE CORROSION OF 356 ALUMINUM IN DEMINERALIZED WATER AT 85°C

Water Condition	Pits per Cm^2	Max. Pit Depth, mils	Removed Wt. Gain, mg/dm^2	Defilmed Wt. Loss, mg/dm^2	Equivalent Thickness Loss, mil/month
Deaerated	0.3	8.4	8.9	5.1	0.006
Aerated	0.9	16.4	15.1	16.4	0.018

The corrosion of 356 aluminum was three times as great in aerated water as in deaerated water, although in either case, the magnitude of this attack was not great. It was observed that in aerated water, the intensity and frequency of pitting attack was increased also. A maximum pit depth of 16.4 mils was reported.

The presence of excess oxygen in the test solutions acted as a stimulant on the corrosion of 356 aluminum. Both normal and localized corrosion attack were noticeably increased. A calculation of the electromotive forces produced when aluminum is exposed to oxygen-free and oxygen-saturated waters substantiates the above experimental data.

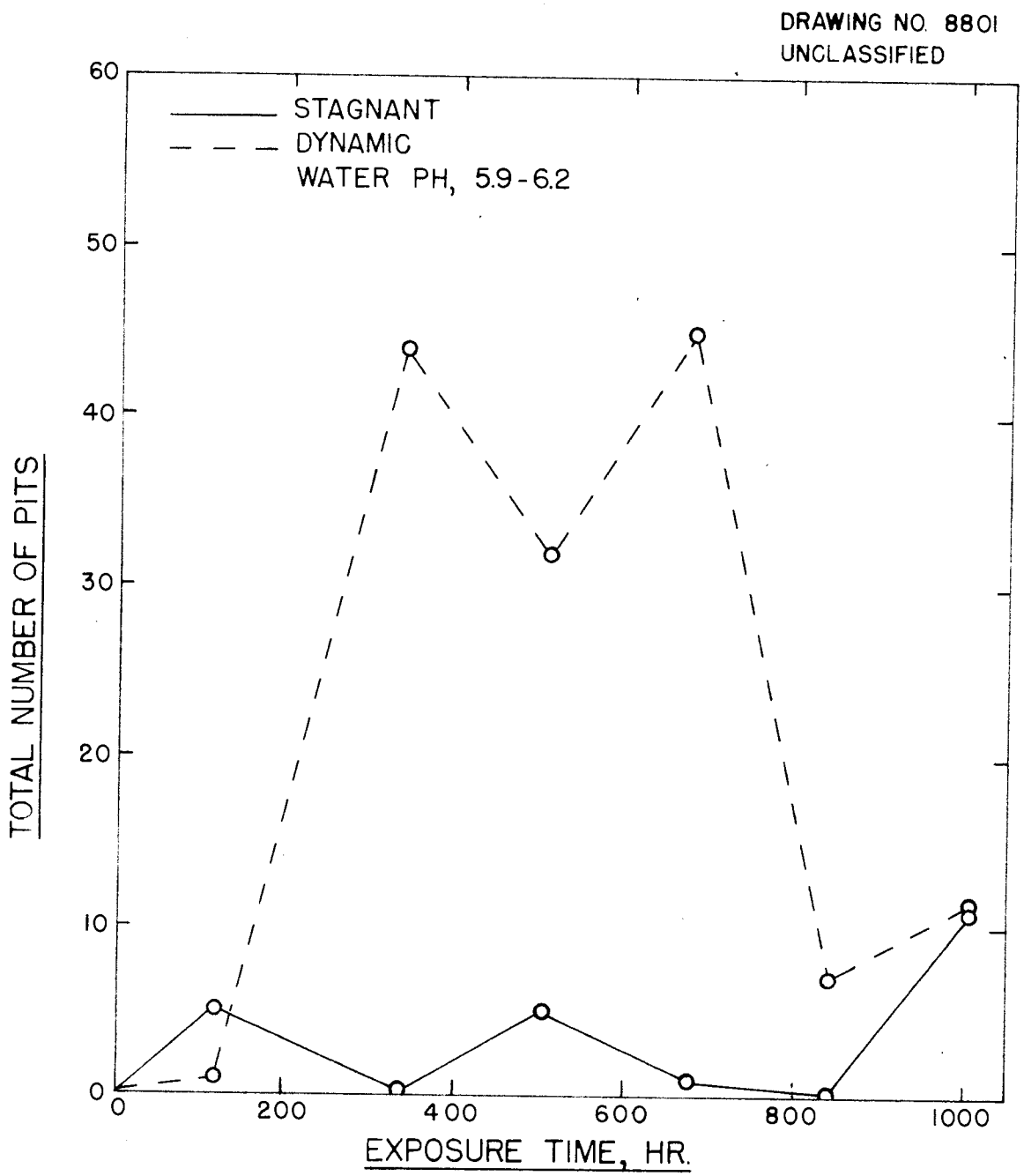

FIG. 3 PITTING FREQUENCY ON STAGNANT AND DYNAMIC 356 ALUMINUM SPECIMENS EXPOSED TO DEMINERALIZED WATER AT 85°C

7.2 Demineralized Water Corrosion (Cont'd)

1) Oxygen-free water (corrosion is of the hydrogen type)

At anode areas:

a) $Al(s) = Al^{+++}(aq) + 3e^-$

b) $Al^{+++}(aq) + 3(OH)^- = Al(OH)_3(s)$

$Al(s) + 3(OH)^- = Al(OH)_3 + 3e^-$ $\quad E_o = -2.31$ v.

At cathode areas:

a) $2H_2O + 2e^- = 2(OH)^- + H_2(g)$ $\quad E_o = 0.828$ v.

Total corrosion reaction:

$$2Al(s) + 6H_2O = 2Al(OH)_3(s) + 3H_2(g)$$

$$E = -2.31 + 0.828$$

$$= -1.482 \text{ v.}$$

Therefore, aluminum can corrode in oxygen-free water with a driving force equal to -1.482 volts.

2) Oxygen-saturated water (corrosion is of the oxygen type)

At anode areas:

a) $Al(s) + 3(OH)^- = Al(OH)_3(s) + 3e^-$ $\quad E_o = -2.31$ v.

At cathode areas:

a) $O_2(\text{in air}) + 2H_2O + 4e^- = 4(OH)^-$ $\quad E_o = -0.391$ v.

Total corrosion reaction:

$$4Al(s) + 3O_2 + 6H_2O = 4Al(OH)_3(s)$$

$$E = -2.31 + (-0.391)$$

$$E = -2.701 \text{ v.}$$

7.2 Demineralized Water Corrosion (Cont'd)

The corrosion of aluminum in pure water containing oxygen is a much more spontaneous reaction than the corrosion of aluminum in oxygen-free water. In non-oxidizing solution, the access of dissolved oxygen to the outside of the oxide film causes an increase in electrolytic potentials at localized areas through the formation of oxygen-concentration cells. When such cells exist, anodic solution may occur and the metal will dissolve beneath the oxide film, or the film may flake or be pushed off by corrosion products that form beneath it. This effect of dissolved oxygen is quite apart from the role of oxygen in the repair and maintenance of the protective oxide films.

7.3 The Effect of Temperature on Corrosion

Stagnant corrosion tests were conducted in order to determine the effect of temperature changes on the corrosion resistance of 356 aluminum. These tests were made at temperatures of 30, 50, 70, and 90°C, in demineralized water containing 0.005M hydrogen peroxide. Duplicate test specimens were exposed for 1008 hours in water with a pH of 6.0-6.1. Average test results are shown in Table X.

The greatest corrosion attack on the aluminum specimens occurred at 50°C. At this temperature, the corrosion rate was 0.036 mil/month and the maximum pit depth reported was 8.5 mils. The corrosion attack at 90°C was slightly less in magnitude than attack at 30°C, 0.007 mil/month as compared to 0.011 mil/month. The greatest pit distribution appeared on the specimen exposed to the hydrogen peroxide solution at 30°C. The number of pits reported on this specimen was 5.2 per cm^2.

In conclusion, the corrosion of 356 aluminum in 0.005M hydrogen peroxide solutions is more pronounced at temperatures between 50-70°C than it is at either 30°C or 90°C. Localized attack was more severe at 50°C than at 70°C. Similar results on the corrosion of aluminum and its alloys at various temperatures have been reported by Evans.[1]

The intensity and frequency of pitting attack is shown graphically in Figure 4. The number of pits diminished from 74 at 50°C to 6 at 90°C.

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[1] Corrosion Handbook, H.H.Uhlig, Editor, John Wiley and Sons, Inc., 1948, pages 41-42.

[redacted]

TABLE X

THE EFFECT OF TEMPERATURE ON THE STAGNANT CORROSION OF 356 ALUMINUM IN 0.005M HYDROGEN PEROXIDE AT 85°C

Solution Temp., °C	Exposure hr.	Area, cm^2	Pits per Cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
30	1008	14.11	5.2	2.0	10	9.7	10.62	0.011
50	1008	14.23	4.1	8.5	30	8.1	34.10	0.036
70	1008	14.11	1.0	2.8	35	24.4	15.58	0.016
90	1008	14.23	0.2	2.0	20	24.9	6.33	0.007

[redacted]

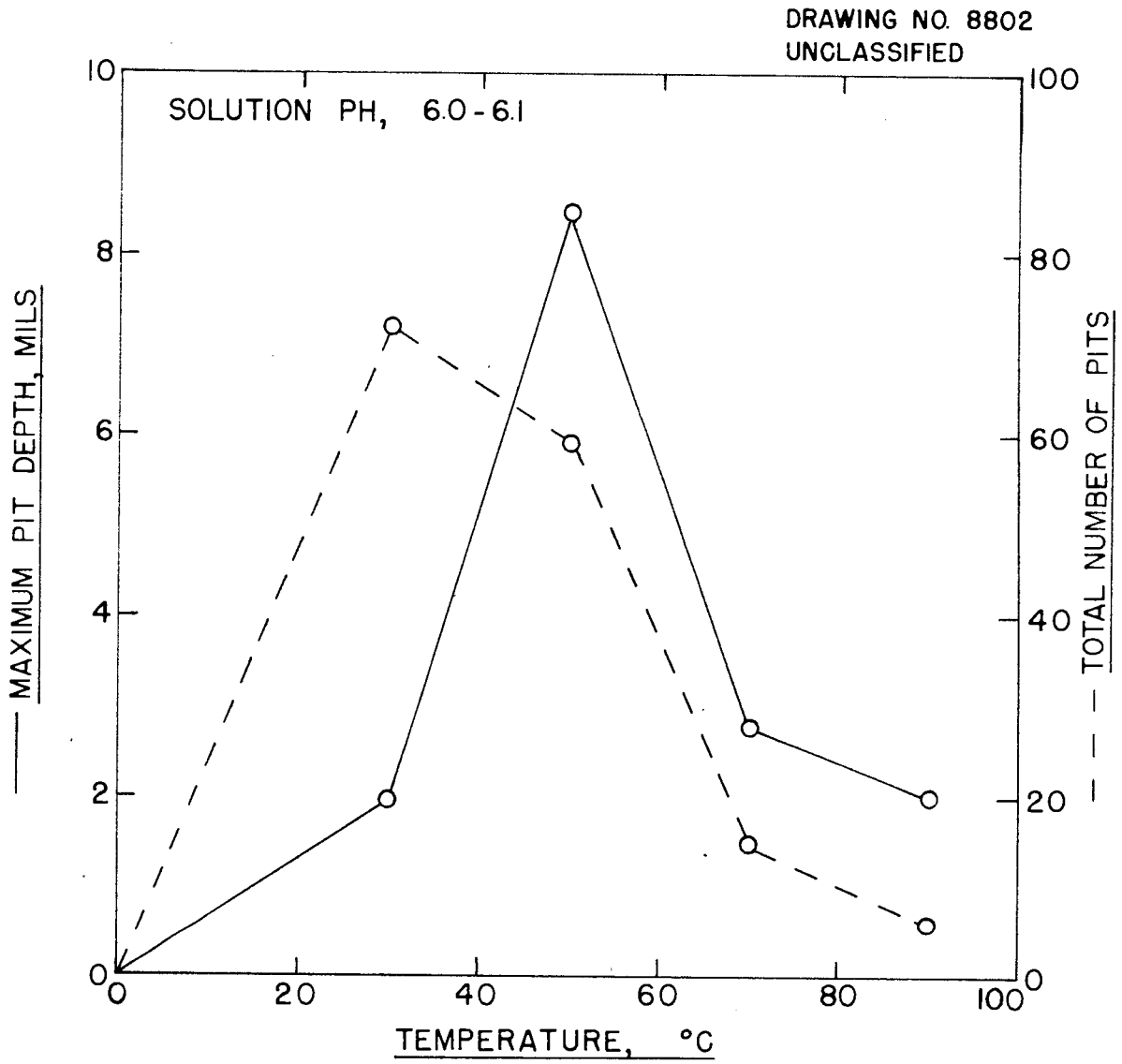

FIG. 4 THE EFFECT OF TEMPERATURE ON LOCALIZED CORROSION ATTACK ON 356 ALUMINUM IN 0.005 M HYDROGEN PEROXIDE

7.4 Corrosion in 0.0005M Hydrogen Peroxide

Hydrogen peroxide in concentrations of 0.0005M was added to demineralized water test solutions in order to simulate the minimum expected concentration of peroxide formation during the operation of the Materials Testing Reactor. Stagnant and dynamic corrosion tests were made at 85°C. Stagnant test results are included in Table XI; the dynamic results are shown in Table XII and are based on average specimen velocities of 6-8 feet/second.

Corrosion attack on 356 aluminum was more intense when exposed under dynamic conditions to 0.0005M hydrogen peroxide. A maximum corrosion rate of 0.137 mil/month in 1008 hours was reported for the dynamic tests as compared to a corrosion rate of 0.002 mil/month for a specimen exposed to stagnant conditions for the same period of time. The appearance of pits on the dynamic specimens was more frequent than on stagnant specimens but the pits were not as deep on the former. A maximum pit depth of 2.8 mils was obtained on the specimens that were rotated. The maximum pit depth on the stagnant specimens was 9.6 mils.

Corrosion weight losses on stagnant specimens increased almost linearly with time for the first 672 hours; after this period, a gradual decrease in the weight losses was observed. Weight losses on the dynamic specimens were erratic. The greatest weight loss, 130.2 mg/dm^2, occurred after 1008 hours of exposure. The weight losses for stagnant and dynamic test specimens are plotted against the exposure time in Figure 5. This graph shows the complete breakdown of the protective oxide film on the dynamic specimens after 672 hours of exposure.

The corrosion process for the dynamic specimens was separated into three distinct phases of 336 hours exposure each. These phases were:

1) An initial or incubation period during which time the protective film formed on the metal surfaces.

2) A protective period during which time the oxide film protected the metal from further corrosion attack.

3) A breakdown period during which corrosion progressed rapidly, probably caused by deterioration of the protective film.

[redacted]

TABLE XI

THE STAGNANT CORROSION OF 356 ALUMINUM IN 0.0005M HYDROGEN PEROXIDE AT 85°C

Solution pH	Exposure hr.	Area, cm^2	Pits per Cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt.Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
6.3	168	14.08	neg.	neg.	neg.	14.90	2.84	0.019
6.3	168	14.08	neg.	neg.	neg.	16.33	3.55	0.023
6.2	336	14.08	neg.	neg.	neg.	16.33	7.10	0.021
6.2	336	14.08	neg.	neg.	neg.	17.75	1.42	0.004
6.2	540	14.08	0.1	9.6	40	20.60	5.67	0.012
6.2	540	14.08	0.1	6.4	20	19.15	10.64	0.026
6.3	672	14.08	0.3	5.2	20	15.60	19.90	0.031
6.3	672	14.08	0.5	4.0	40	17.75	14.90	0.025
6.2	840	14.08	0.9	2.8	40	22.00	4.97	0.006
6.2	840	14.08	0.3	1.8	10	17.75	3.55	0.004
6.0	1008	14.08	neg.	neg.	neg.	26.25	8.52	0.008
6.0	1008	14.08	neg.	neg.	neg.	27.68	7.10	0.007
6.2	1240	15.70	neg.	neg.	neg.	22.30	2.55	0.002
6.2	1240	15.67	neg.	neg.	neg.	24.30	3.83	0.003
6.2	1240	15.67	neg.	neg.	neg.	36.40	neg.	neg.

[redacted]

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TABLE XII

THE DYNAMIC CORROSION OF 356 ALUMINUM IN 0.005M HYDROGEN PEROXIDE AT 85°C

Solution pH	Exposure hr.	Area, cm^2	Pits per Cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
6.2	168	13.90	1.6	0.8	20	0.72	5.76	0.035
6.1	336	13.90	1.1	0.8	20	10.28	19.43	0.058
6.1	504	13.90	neg.	neg.	neg.	4.32	10.30	0.023
6.0	672	14.29	1.4	0.8	10	17.19	4.23	0.007
6.2	840	13.90	1.0	0.8	20	14.40	55.40	0.070
6.1	1008	13.90	1.0	2.8	20	33.81	130.20	0.137

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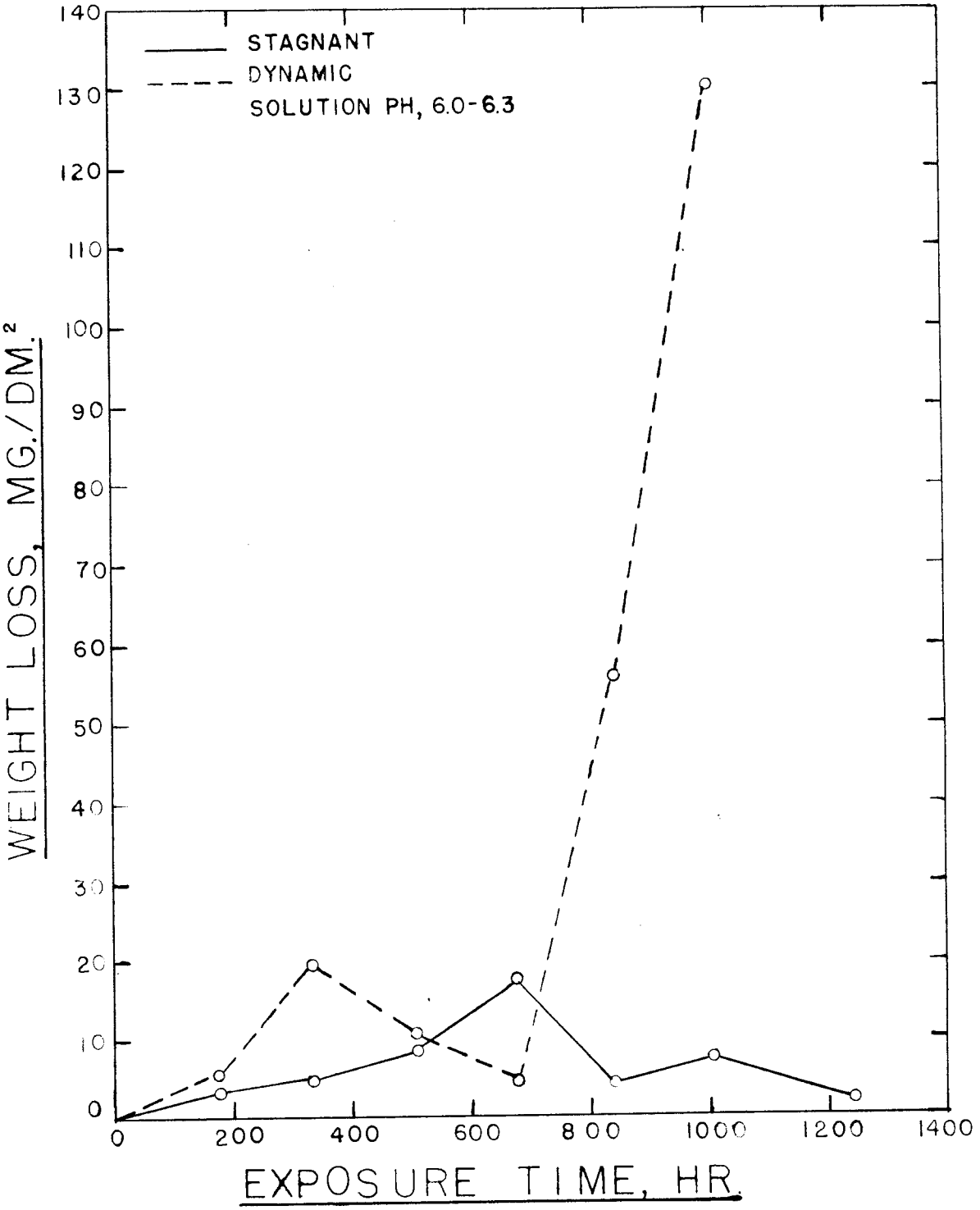

FIG. 5 THE STAGNANT AND DYNAMIC CORROSION OF 356 ALUMINUM IN 0.0005 M HYDROGEN PEROXIDE AT 85° C

7.4 Corrosion in 0.0005M Hydrogen Peroxide (Cont'd)

With the exception of a portion of the dynamic corrosion tests, the presence of 0.0005M hydrogen peroxide appeared beneficial for the corrosion resistance of 356 aluminum. A definite decrease in the normal corrosion rate of the aluminum was observed as compared to similar tests in deaerated water. This was true for the largest number of stagnant and dynamic test specimens. It was evident that localized corrosion attack was reduced markedly in the 0.0005M peroxide solutions.

A comparison of weight losses for stagnant and dynamic test specimens in deaerated water and 0.0005M hydrogen peroxide is shown in Table XIII. These weight losses are reported as defilmed weight losses after the oxide film and corrosion products have been removed by chemical defilming treatments.

7.5 Corrosion in 0.005M Hydrogen Peroxide

The maximum concentration of hydrogen peroxide expected as a result of irradiation effects on the cooling water in the Materials Testing Reactor was 0.005M. The corrosion resistance of 356 aluminum was investigated under stagnant and dynamic conditions in demineralized water at 85°C containing 0.005M peroxide concentration. Data for these tests are included in Tables XIV and XV.

Weight losses on the stagnant specimens gradually decreased during exposures up to 1240 hours. At the end of this time, the corrosion rate averaged 0.007 mil/month. The initial corrosion rate was considerably higher as would be expected due to the time required for the formation of the protective film on the essentially oxide-free metal surfaces. A maximum pit depth of 12 mils was observed after 1240 hours of test. The greatest frequency of pitting attack occurred during the 500-700 hours exposure period. Values of the number of pits per sq cm ranged from 3.7 to 7.4 for this test time.

The dynamic test specimens showed a gradual increase in weight losses as the exposure time approached 1008 hours. The corrosion rates were generally higher than rates for stagnant specimens. For 1008 hours, the equivalent thickness loss was 0.033 mil/month; at the end of 168 hours, it was 0.049 mil/month. Pitting attack on these specimens was not as intense as on the stagnant samples. A maximum pit depth of 4.0 mils was observed; the maximum pit count (pits/sq cm) was 2.9. The overall effect of velocity on localized corrosion attack of the 356 aluminum has been to reduce the intensity and frequency of pits. This reduction may be attributed to the fact that during conditions of movement, there is no opportunity for stagnant areas or layers to form at the liquid-metal interfaces.

[redacted]

TABLE XIII

A COMPARISON OF THE CORROSION ON 356 ALUMINUM IN DEAERATED WATER AND 0.0005M HYDROGEN PEROXIDE

Exposure hr.	Stagnant Tests		Dynamic Tests	
	Deaerated	0.0005M	Deaerated	0.0005M
168	9.90	3.20	21.85	5.76
336	11.21	4.26	22.15	19.43
504	11.31	8.16	22.90	10.30
672	5.30	17.40	18.33	4.23
840	6.33	4.26	17.60	55.40
1008	8.83	7.31	30.54	130.20

Note: Weight losses are expressed as mg./dm.^{2}

[redacted]

[redacted]

TABLE XIV

THE STAGNANT CORROSION OF 356 ALUMINUM IN 0.005M HYDROGEN PEROXIDE AT 85°C

Solution pH	Exposure hr.	Area, cm^2	Pits per Cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
6.3	168	14.28	neg.	neg.	neg.	24.80	12.08	0.075
6.3	168	14.28	neg.	neg.	neg.	23.45	8.52	0.053
6.3	336	14.28	0.07	3.6	10	27.33	5.61	0.017
6.3	336	14.28	0.07	3.8	30	21.72	9.11	0.029
6.2	504	14.28	4.0	1.2	40	5.60	17.50	0.028
6.2	504	14.28	3.4	0.8	20	6.30	11.20	0.018
6.2	672	14.28	7.5	1.9	40	25.50	7.70	0.016
6.2	672	14.28	7.2	2.8	20	27.30	3.50	0.007
6.2	840	14.28	1.1	6.4	24	21.10	9.10	0.012
6.2	840	14.28	1.3	3.6	12	30.80	10.51	0.013
6.1	1008	14.28	neg.	neg.	neg.	27.30	5.61	0.006
6.1	1008	14.28	neg.	neg.	neg.	28.10	4.91	0.005
6.2	1240	15.70	neg.	neg.	neg.	38.85	11.46	0.010
6.2	1240	15.67	0.5	12.0	12.0	45.20	3.82	0.003
6.2	1240	15.67	neg.	neg.	neg.	42.65	8.27	0.007

[redacted]

[redacted]

TABLE XV

THE DYNAMIC CORROSION OF 356 ALUMINUM IN 0.005M HYDROGEN PEROXIDE AT 85°C

Solution pH	Exposure hr.	Area, cm^2	Pits per Cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
6.1	168	14.23	0.6	0.6	4	13.35	7.73	0.049
6.1	336	14.23	2.5	4.0	30	7.73	11.23	0.036
6.1	504	13.82	2.9	3.2	20	13.74	1.45	0.003
6.1	672	14.13	1.0	1.6	30	14.15	16.97	0.027
6.1	840	14.23	neg.	neg.	neg.	15.45	24.59	0.031
6.1	1008	14.17	1.3	3.6	40	36.70	31.05	0.033

[redacted]

7.5 Corrosion in 0.005M Hydrogen Peroxide (Cont'd)

Such stagnant areas invariably result in concentration cell formations which tend to greatly stimulate localized attack. During movement of the specimen, fresh solution is continually brought into contact with the metallic surfaces and there is no chance for such cells to develop. The weight losses on the stagnant and dynamic specimens are plotted in Figure 6; corrosion rates are shown as a function of exposure time in Figure 7.

The test data show that all specimens increased in weight during the exposure periods and no specimen exhibited a weight loss as removed from the test solution. The defilmed weight loss, corrected for weight loss of the base metal by the defilming solution, indicates the amount of base metal which has entered into combination with oxygen to form the surface films. Assuming that these films are tightly adherent, the amount of metal entering into such combination can be determined quantitatively using the hydrated oxide formula of $\alpha.Al_2O_3.H_2O$ for the film formed between 70-100°C. Errors will be introduced into this determination by the presence of other elements, such as silicon in 356 aluminum, which also enter into combination with various ions in the corrosion medium, thus adding to the complexity of the protective film.

Table XVI lists comparative corrosion data for 356 aluminum exposed to deaerated water, 0.0005M hydrogen peroxide, and 0.005M hydrogen peroxide under stagnant and dynamic conditions. Weight losses, mg/dm^2, are reported as a function of the test exposure time.

For the stagnant tests, the order of decreasing corrosiveness of the test media was; deaerated water, 0.0005M hydrogen peroxide, and 0.005M hydrogen peroxide. For the dynamic tests, the order of decreasing corrosiveness of the test media was; 0.0005M hydrogen peroxide, deaerated water, and least corrosive, 0.005M hydrogen peroxide. Thus, it appears that for stagnant and dynamic conditions, the corrosion resistance of 356 aluminum in 0.005M hydrogen peroxide is superior to the resistance in either deaerated water or 0.0005M hydrogen peroxide solutions.

7.6 The Effect of Chemical Inhibitors

Several inorganic chemicals, sodium chromate and sodium dichromate, were investigated as possible corrosion inhibitors for 356 aluminum under the conditions of exposure. These compounds are commonly used to inhibit corrosion attack on aluminum alloys under various conditions.

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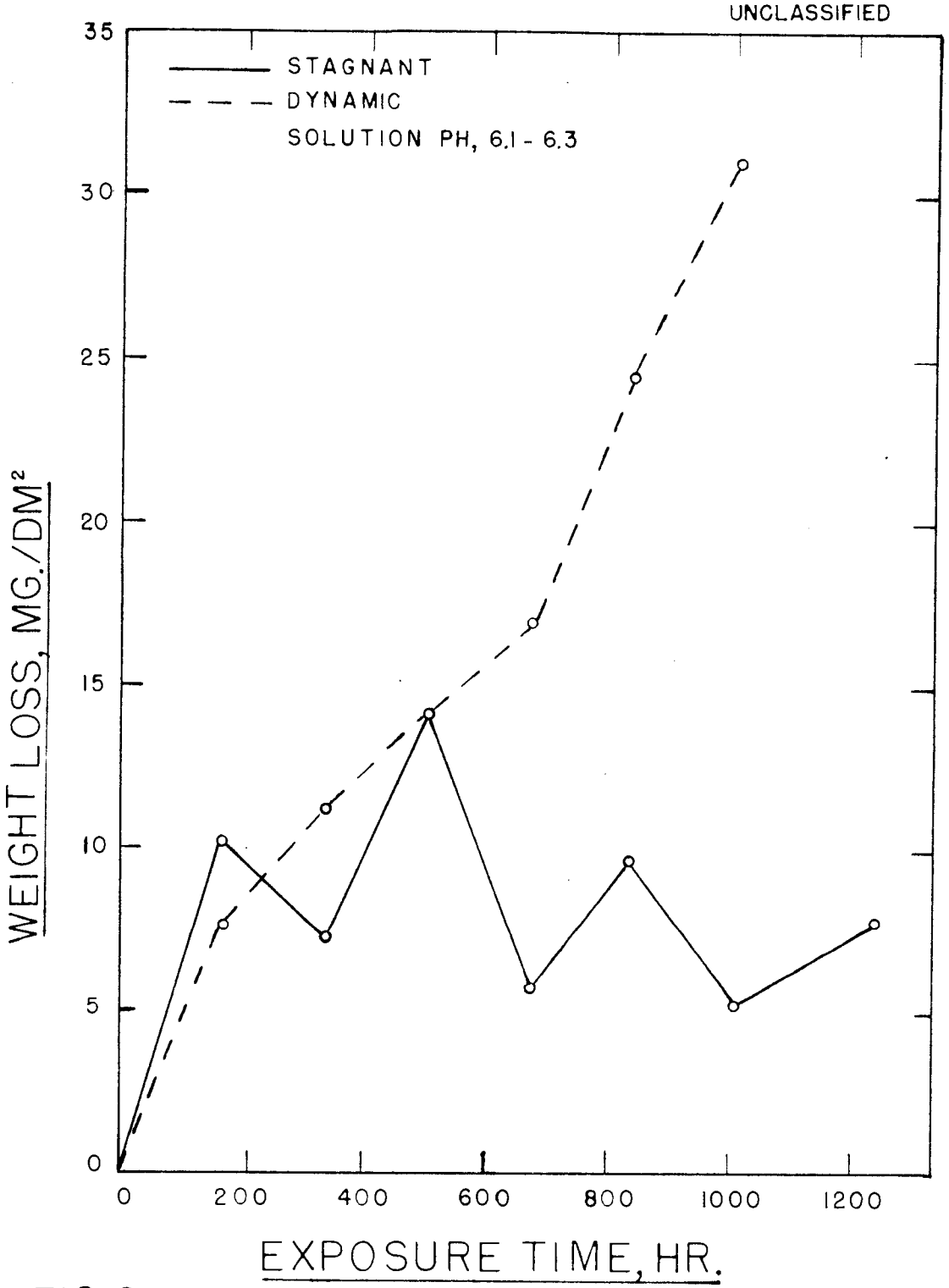

FIG. 6 THE STAGNANT AND DYNAMIC CORROSION OF 356 ALUMINUM IN 0.005M HYDROGEN PEROXIDE AT 85°C

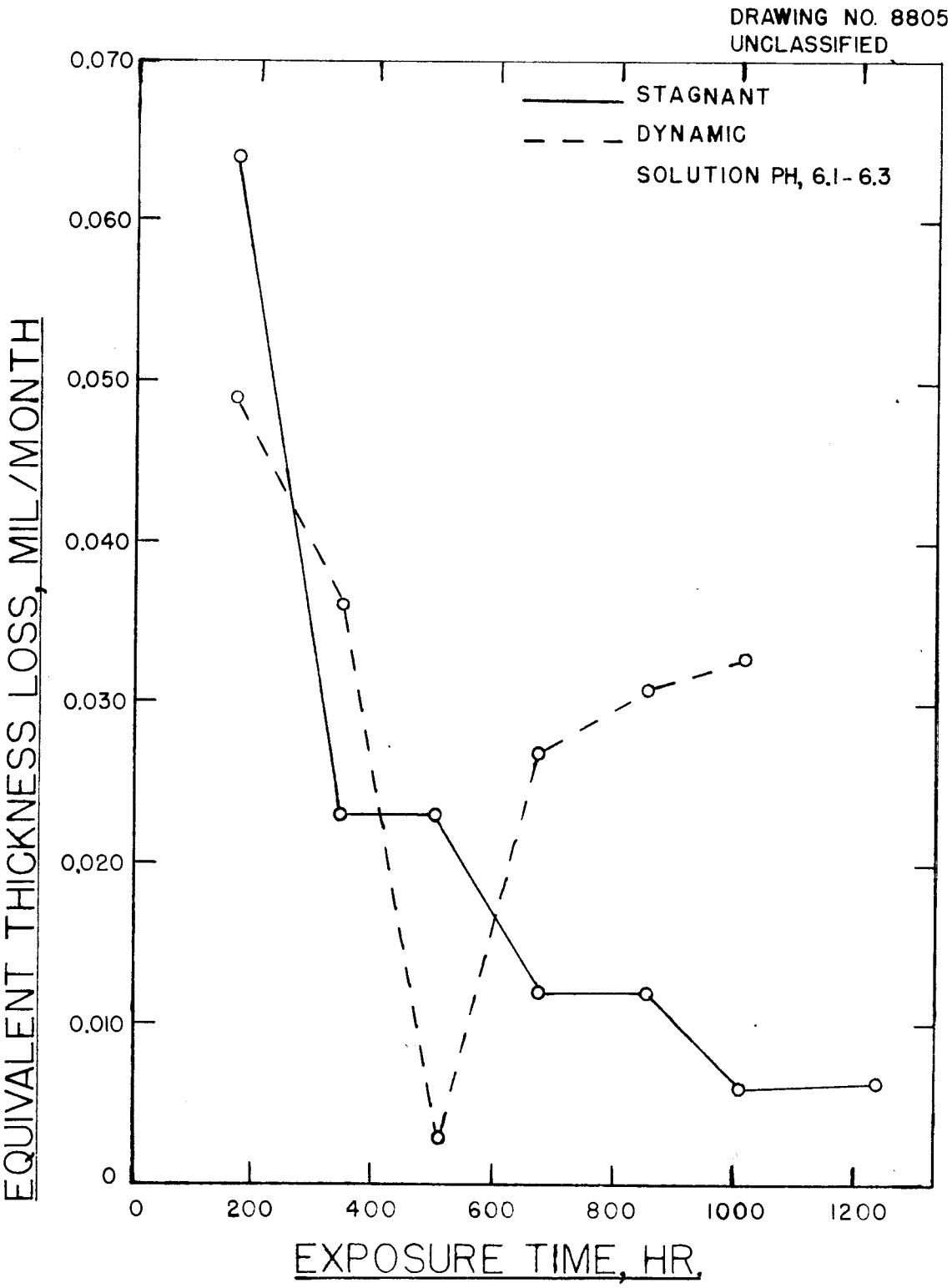

FIG. 7 THE STAGNANT AND DYNAMIC CORROSION OF 356 ALUMINUM IN 0.005M HYDROGEN PEROXIDE AT 85°C

[redacted]

TABLE XVI

A COMPARISON OF THE WEIGHT LOSS ON 356 ALUMINUM EXPOSED TO DEAERATED WATER AND 0.0005M-0.005M HYDROGEN PEROXIDE SOLUTIONS AT 85°C

Exposure hr.	Stagnant Tests			Dynamic Tests		
	Deaerated	0.0005M	0.005M	Deaerated	0.0005M	0.005M
168	9.90	3.20	10.30	4.85	5.76	7.73
336	11.21	4.26	7.36	22.15	19.43	11.23
504	11.31	8.16	14.40	22.90	10.30	1.45
672	5.30	17.40	5.60	18.33	9.23	16.97
840	6.33	4.26	9.80	17.60	55.40	24.59
1008	8.83	7.31	5.27	30.54	130.20	31.05

Note: Weight losses are expressed as mg./dm.^{2}

[redacted]

7.6 The Effect of Chemical Inhibitors (Cont'd)

A chemical or substance may be classified as a corrosion inhibitor if it has the property of reducing the total corrosion on a metal or alloy when added in small amounts to the corrosive environment. The mechanism of inhibitor action is quite complex but a simplified expression of the means by which inhibitors function is shown in the following equation.[1]

$$I_{max.} = E_o - \frac{(E_a + E_c)}{R}$$

$I_{max.}$ = the rate of corrosion attack based on current intensity
E_o = the open circuit potential between the local anodes and cathodes
E_a = the anodic polarization
E_c = the cathodic polarization
R = the resistance of the liquid path

From an electrochemical viewpoint, an inhibitor, to be effective, must do one or more of the following:

1) Increase the resistance (R) of the electrolytic path between the local anodes and cathodes.

2) Increase the polarization (E_a) of the local anodes.

3) Increase the polarization (E_c) of the local cathodes.

4) Decrease the open circuit potential (E) between the local anodes and cathodes.

The addition of soluble chromates, phosphates, silicates, or hydroxides to corrosive media to reduce the corroion rate of some metals and alloys (among which is aluminum) serves as an example of anodic inhibition since these substances increase the magnitude of E_a, the anodic polarization value. These materials aid in forming or repairing the protective film on the metal.

Anodic inhibitors may be either safe or dangerous, depending upon the exposure conditions, inhibitor concentrations, and other factors. A safe inhibitor is one which diminishes the corrosion velocity without increasing the intensity of corrosion attack. A dangerous inhibitor is one which diminishes the corrosion velocity

[1] R. B. Mears and G. G. Eldredge, Trans, of the Electro. Soc. No. 83, 4, 1942.

7.6 The Effect of Chemical Inhibitors (Cont'd)

but increases the intensity of attack, resulting in early material failure by pitting or perforation. An example of the latter type results when insufficient amounts of the inhibitor are added to a system where the corrosion process is under cathodic control. The addition of insufficient chromate to completely stifle oxygen-type corrosion attack on iron, steel, zinc, and aluminum has been shown to cause serious intensification of attack.[1] If the amount of chromate is increased, the corrosion process will be brought under anodic control and complete protection will result. The amount of chromate necessary to eliminate pitting and offer complete protection will depend greatly on the concentrations of sulfate and chloride ions present in the corrosive media. These ions hinder the development of a protective film because of their extreme smallness and high penetrating power, enabling them to pass through the film and attack the base metal.

7.6.1 Sodium Chromate

An aqueous stock solution of sodium chromate was prepared from C.P. Na_2CrO_4. The concentration of this solution was such that one milliliter supplied 10 ppm of sodium chromate to 4 liters of test solution. Corrosion tests were conducted under stagnant conditions in deaerated water, 0.0005M hydrogen peroxide, and 0.005M hydrogen peroxide solutions. Two solution pH ranges were used, 5.5-6.5 and 7.5-8.0. Test temperatures were maintained at 85°C. Test data and results are shown in Tables XVII, XVIII, XIX, and XX.

By far the most serious corrosion attack suffered by the 356 aluminum was in the test solutions in which the solution pH was maintained between 7.5 and 8.0. All specimens were heavily etched and a maximum corrosion rate of 0.512 mil/month was obtained for a sample exposed for 840 hours. Prolific localized attack was observed on three of the specimens. Sodium chromate under these test conditions greatly accelerated the corrosion attack and was classed as a dangerous inhibitor.

When the water pH was adjusted between 5.5 and 6.5, corrosion attack on the specimens was minimized by the presence of 10 ppm of

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[1] Corrosion Handbook, H. H. Uhlig, Editor, John Wiley and Sons, Publishers, 1948, page 908.

[redacted]

TABLE XVII

THE STAGNANT CORROSION OF 356 ALUMINUM IN DEAERATED WATER CONTAINING 10 PPM. OF SODIUM CHROMATE AT 85°C

Solution pH	Exposure hr.	Area, cm^2	Pits per Cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt.Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
6.2	168	14.23	neg.	neg.	neg.	3.51	0.72	0.004
6.1	336	14.23	neg.	neg.	neg.	4.92	2.11	0.007
6.1	504	14.00	neg.	neg.	neg.	7.14	neg.	neg.
6.1	672	14.26	neg.	neg.	neg.	12.62	neg.	neg.
6.0	840	14.26	neg.	neg.	neg.	3.51	neg.	neg.
6.2	1008	14.26	neg.	neg.	neg.	9.12	neg.	neg.

[redacted]

[redacted]

TABLE XVIII

THE STAGNANT CORROSION OF 356 ALUMINUM IN 0.0005M HYDROGEN PEROXIDE CONTAINING 10 PPM. OF SODIUM CHROMATE AT 85°C

Solution pH	Exposure hr.	Area, cm^2	Pits per Cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
6.2	168	14.36	neg.	neg.	neg.	6.72	2.09	0.013
6.1	336	13.82	neg.	neg.	neg.	20.25	9.40	0.030
6.1	504	14.09	neg.	neg.	neg.	37.60	7.81	0.017
6.1	672	14.18	neg.	neg.	neg.	35.30	0.71	0.002
6.1	840	14.09	neg.	neg.	neg.	20.60	1.42	0.002
6.1	1008	14.09	1.6	0.8	10	41.85	12.78	0.013

[redacted]

[redacted]

TABLE XIX

THE STAGNANT CORROSION OF 356 ALUMINUM IN 0.0005M HYDROGEN PEROXIDE CONTAINING 10 PPM. OF SODIUM CHROMATE AT 85°C

Solution pH	Exposure hr.	Area, cm^2	Pits per Cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
7.5	168	14.19	num.	0.4	10	17.62	57.80	0.365
7.5	336	14.28	num.	0.9	20	16.80	148.50	0.468
7.7	504	14.19	2.6	1.2	24	-73.35[1]	177.50	0.374
7.8	672	14.28	Surfaces heavily etched			-107.3[1]	289.8	0.457
7.8	840	13.82	Surfaces heavily etched			-83.8[1]	404.5	0.512
7.8	1008	13.98	Surfaces heavily etched			-141.0[1]	428.5	0.453

[1] Specimen showed a weight loss as removed from the test solution

[redacted]

[redacted]

TABLE XX

THE STAGNANT CORROSION OF 356 ALUMINUM IN 0.005M HYDROGEN PEROXIDE CONTAINING 10 PPM. OF SODIUM CHROMATE AT 85°C

Solution pH	Exposure hr.	Area, cm^2	Pits per Cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt.Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
6.2	168	14.19	14.3	0.8	80	12.68	1.41	0.009
6.1	336	13.90	1.7	0.8	10	17.98	16.54	0.051
6.1	504	13.90	neg.	neg.	neg.	23.02	11.51	0.024
6.1	672	13.90	4.1	12.0	70	34.53	8.63	0.014
6.2	840	13.90	7.2	1.2	20	12.95	1.44	0.002
6.2	1008	14.19	11.9	1.2	10	28.15	24.65	0.026

[redacted]

7.6.1 Sodium Chromate (Cont'd)

sodium chromate. The order of decreasing effectiveness of the chromate in the various media was; deaerated water, 0.0005M hydrogen peroxide, and 0.005M hydrogen peroxide. In all cases, the magnitude of corrosion attack was very minor. In many instances, especially in deaerated water and 0.0005M hydrogen peroxide, pitting attack was completely eliminated. In the 0.005M hydrogen peroxide solutions, pitting attack was more abundant but the pit depths did not exceed an average of 0.8 mil. Figure 8a, 8b, and 8d show the effect of increased availability of oxygen on the corrosion of 356 aluminum. These graphs indicate that an incubation period of approximately 350 hours was required before corrosion attack was diminished by the formation of the protective film. In Figure 8a, the film remained completely protective for the balance of the test. However, in Figure 8b and 8d, the film was observed to lose its protective nature after 700-800 hours and corrosion attack progressed rapidly.

These test data show that the presence of oxygen in the test solution plays an important role in determining the effectiveness of the sodium chromate inhibitor. In deaerated water, nearly complete protection was obtained. As hydrogen peroxide was increased from 0.0005M to 0.005M in concentration, the effectiveness of the inhibitor became less, and corrosion attack was most pronounced in the 0.005M peroxide solutions. The pH of the demineralized water was another important factor in determining the effectiveness of the chromate as a corrosion inhibitor. If the pH was maintained between 7.5 and 8.0, corrosion attack was extremely severe. The pH best suited for the maximum benefit from the inhibitor was 5.5-6.5.

A comparison of weight losses on 356 aluminum in uninhibited test solutions and in solutions containing sodium chromate is shown in Table XXI. The sodium chromate concentration was 10 ppm in all tests and the time duration of the tests was 1008 hours.

7.6.2 Sodium Dichromate

The effectiveness of sodium dichromate as a corrosion inhibitor for 356 aluminum was studied in a series of stagnant tests. This particular chemical was selected for study since it is used successfully as an inhibitor for aluminum systems handling recirculating hot or cold water. The amount of dichromate used for such conditions is approximately 0.1 percent and the water in the system is made slightly basic.

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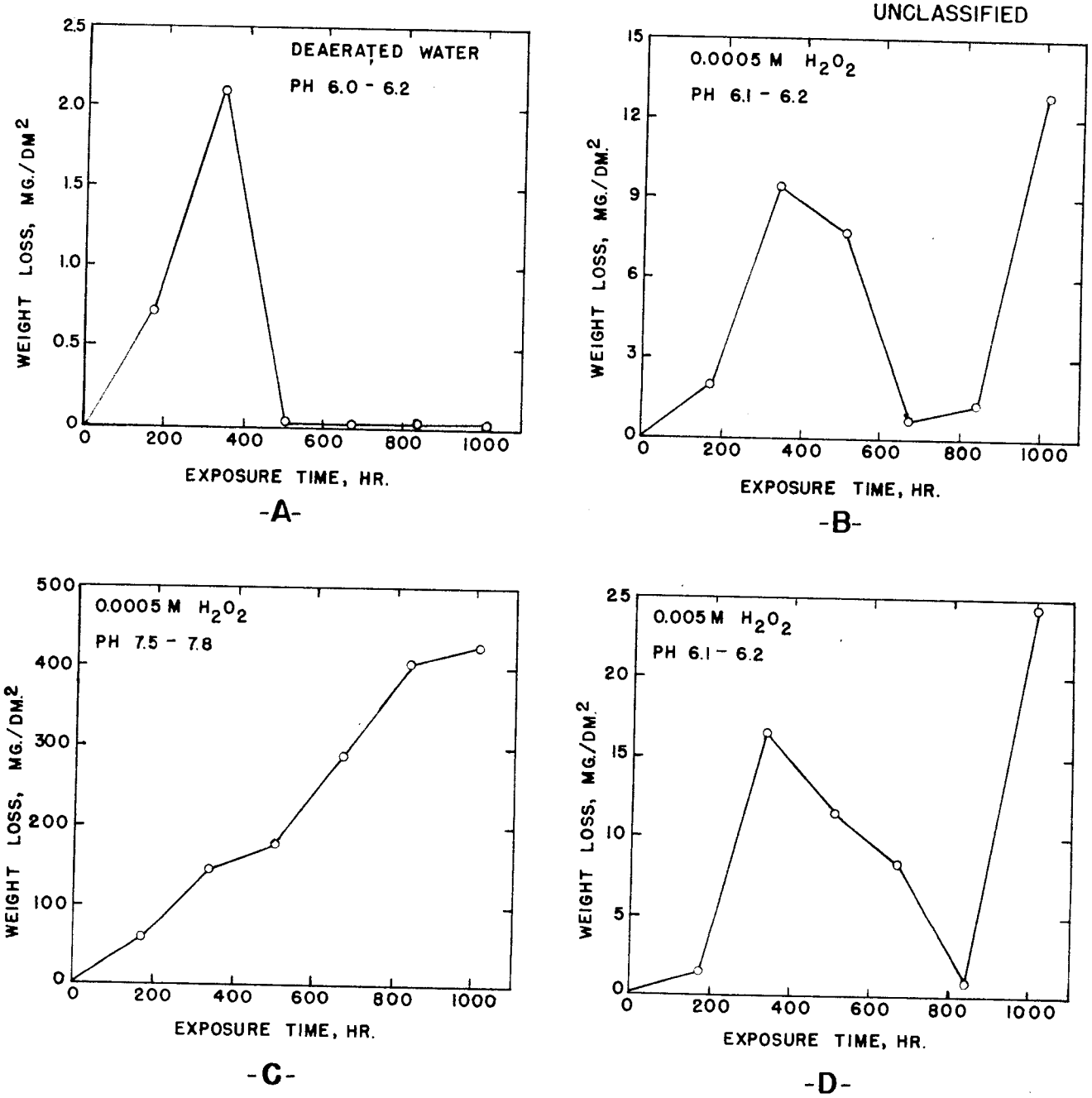

FIG. 8 STAGNANT CORROSION OF 356 ALUMINUM IN VARIOUS MEDIA CONTAINING 10 PPM. OF SODIUM CHROMATE AT 85°C

[redacted]

TABLE XXI

A COMPARISON OF THE CORROSION ATTACK ON 356 ALUMINUM EXPOSED TO VARIOUS UNIHIBITED AND INHIBITED TEST MEDIA AT 85°C

Test Medium	Max. Pit Count, no./cm^2	Max. Pit Depth, mils	Max. Pit Diameter, mils	Max. Weight Loss, mg./dm^2
Deaerated water	1.6 (neg.)	13.7 (neg.)	60 (neg.)	11.31 (2.11)
0.0005M H_2O_2	0.9 (1.6)	9.6 (0.8)	40 (10)	17.40 (12.78)
0.005M H_2O_2	7.5 (14.3)	12.0 (12.0)	40 (80)	14.35 (24.65)

Notes:
1) Tests were conducted for 1008 hours with a solution pH range of 5.5-6.5.
2) Figures in parentheses represent corrosion data for test solutions containing 10 ppm. of sodium chromate.
3) Tests were made under stagnant conditions.

[redacted]

7.6.2 Sodium Dichromate (Cont'd)

The concentration of sodium dichromate used in the corrosion tests was 5 ppm and the pH of the water was adjusted to 7.5-8.0 by the addition of small quantities of dilute sodium hydroxide. The tests were conducted at 85°C.

Corrosion data for 356 aluminum in 0.0005M and 0.005M hydrogen peroxide solutions are shown in Tables XXII and XXIII. Weight losses on the specimens are plotted against the exposure time in Figure 9.

These data show definitely that the corrosion of 356 aluminum was accelerated in hydrogen peroxide solutions by the presence of 5 ppm of sodium dichromate. This acceleration was more pronounced in the 0.005M peroxide solutions, although pitting attack was reduced to negligible proportions. Pitting attack on the specimens exposed to 0.0005M hydrogen peroxide was not completely eliminated in all cases. The weight losses on the specimens and the corrosion rates were far more severe than encountered for 356 aluminum in similar uninhibited test solutions. In 0.0005M hydrogen peroxide solution containing 5 ppm of sodium chromate, the corrosion on the aluminum alloy was increased 30 times in magnitude over the corrosion rate obtained in uninhibited 0.0005M peroxide; in inhibited 0.005M hydrogen peroxide, the corrosion rate was nearly 40 times greater than observed in uninhibited 0.005M peroxide.

Based upon these results, the use of sodium dichromate in concentrations of 5 ppm is classified as dangerous for 356 aluminum in hydrogen peroxide solutions at 85°C. A mild reduction in the intensity and frequency of pitting attack was noted in a few cases, especially in 0.005M hydrogen peroxide, but this beneficial influence if offset by the severe increase in the normal corrosion rate for the alloy.

7.7 The Effect of Heat Treatment on Corrosion

As mentioned in Section 5.3, two types of 356 aluminum were considered for use in the water-cooled reactor and corrosion tests were conducted on both types. Cast and heat treated forms of the alloy were used. The cast material was sand-cast, and the heat treated alloy was subjected to the T-7 heating cycle. The advantage of the heat treatment is found in increased values for tensile, yield, and shear strengths

Table XXIV shows corrosion data for the cast 356 aluminum exposed to 0.0005M and 0.005M hydrogen peroxide solutions under stagnant conditions at 85°C. In general, the corrosion resistance

[redacted]

TABLE XXII

THE STAGNANT CORROSION OF 356 ALUMINUM IN 0.0005M HYDROGEN PEROXIDE AT 85°C CONTAINING 5 PPM. OF SODIUM DICHROMATE

Solution pH	Exposure hr.	Area, cm^2	Pits per cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
7.8	168	14.02	0.6	3.6	4.0	30.65	29.22	0.185
7.8	336	15.35	0.5	0.7	4.0	25.40	27.80	0.119
7.8	504	12.11	neg.	neg.	neg.	36.33	147.80	0.310
7.8	672	15.65	2.5	5.6	60	-14.60[1]	92.65	0.146
7.8	840	13.83	neg.	neg.	neg.	24.94	127.00	0.148
7.8	1008	12.11	neg.	neg.	neg.	-42.15[1]	247.50	0.250

[1] Specimen showed a weight loss as removed from the test solution.

[redacted]

[redacted]

TABLE XXIII

THE STAGNANT CORROSION OF 356 ALUMINUM IN 0.005M HYDROGEN PEROXIDE CONTAINING 5 PPM. OF SODIUM DICHROMATE AT 85°C

Solution pH	Exposure hr.	Area, cm^2	Pits per Cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt.Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
7.8	168	13.14	neg.	neg.	neg.	22.05	18.25	0.115
7.7	168	14.19	neg.	neg.	neg.	-27.50[1]	104.30	0.658
7.8	336	14.05	neg.	neg.	neg.	19.21	22.05	0.069
7.7	336	14.09	neg.	neg.	neg.	-16.33[1]	144.80	0.457
7.8	504	14.05	neg.	neg.	neg.	12.81	71.75	0.151
7.7	504	13.79	neg.	neg.	neg.	35.35	121.80	0.256
7.8	672	14.03	neg.	neg.	neg.	2.14	86.25	0.136
7.7	672	13.99	neg.	neg.	neg.	-20.71[1]	111.50	0.176
7.8	840	14.31	neg.	neg.	neg.	11.17	83.80	0.106
7.7	840	14.19	neg.	neg.	neg.	-38.05[1]	272.50	0.344
7.8	1008	14.21	neg.	neg.	neg.	35.90	152.90	0.160
7.7	1008	14.19	neg.	neg.	neg.	-33.12[1]	262.50	0.276

[1] Specimen showed a weight loss as removed from the test solution

[redacted]

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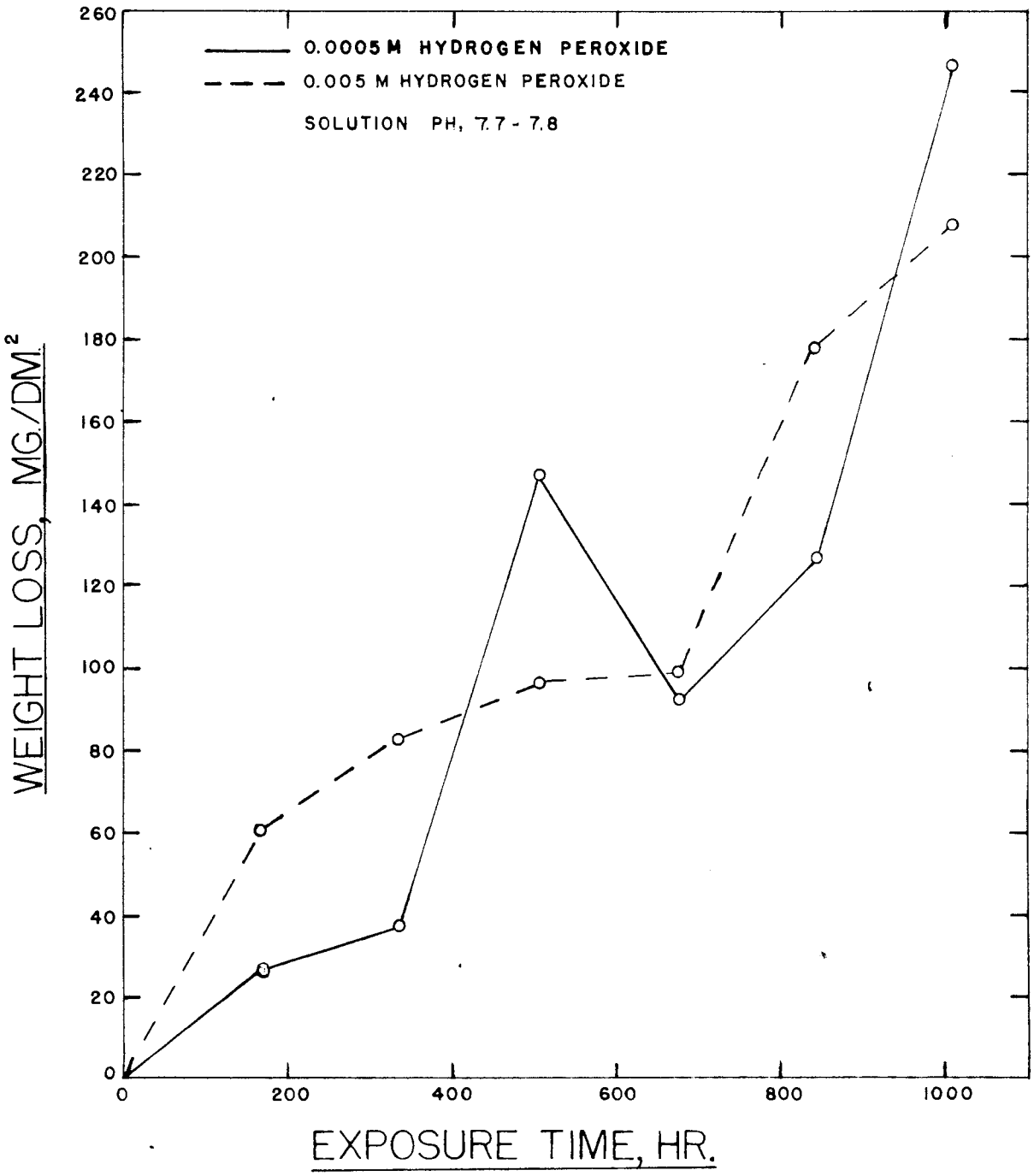

FIG. 9 THE STAGNANT CORROSION OF 356 ALUMINUM IN HYDROGEN PEROXIDE SOLUTIONS CONTAINING 5 PPM. OF SODIUM DICHROMATE AT 85°C

[redacted]

TABLE XXIV

THE STAGNANT CORROSION OF CAST 356 ALUMINUM IN HYDROGEN PEROXIDE SOLUTIONS AT 85°C

Solution pH	Exposure hr.	Area, cm^2	Pits per cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
6.1	191	15.45	neg.	neg.	neg.	7.77	3.23	0.018[1]
6.1	330	15.75	1.0	12.0	80	12.05	1.91	0.006[1]
6.1	498	15.45	neg.	neg.	neg.	11.65	neg.	neg[1]
6.1	666	15.45	0.5	1.2	20	12.95	4.56	0.007[1]
6.1	763	15.75	0.4	8.0	40	19.65	4.44	0.006[1]
6.1	936	15.45	0.9	22.6	40	11.64	9.71	0.011[1]
6.2	1240	15.67	neg.	neg.	neg.	19.15	6.37	0.005[1]
6.2	1240	15.67	neg.	neg.	neg.	26.15	10.21	0.009[1]
6.2	1240	15.67	neg.	neg.	neg.	44.10	9.57	0.008[2]
6.2	1240	15.67	neg.	neg.	neg.	52.95	5.11	0.004[2]

[1] Test solution was 0.0005M hydrogen peroxide

[2] Test solution was 0.005M hydrogen peroxide

[redacted]

7.7 The Effect of Heat Treatment on Corrosion (Cont'd)

of the cast alloy was slightly superior to that of the heat treated alloy exposed to similar conditions. This superiority was more pronounced during the initial exposure period. The corrosion resistance of both types of material in 0.0005M hydrogen peroxide was nearly identical for periods of 1000-1240 hours. In 0.005M hydrogen peroxide, for the same periods of exposure, the corrosion resistance of the cast alloy was slightly better than the heat treated alloy.

Pitting attack was almost the same in frequency and intensity on both forms of the alloy in 0.0005M hydrogen peroxide solution. An average pit depth of 5.4 mils was observed and the average pit distribution was 0.4 pits/sq cm. Pitting attack on cast specimens exposed to 0.005M hydrogen peroxide was negligible.

A comparison of weight losses vs. exposure time for cast 356 aluminum and heat treated 356 aluminum is shown in Figure 10. The superiority of cast 356 aluminum during the first 800 hours of exposure is clearly illustrated.

8.0 GALVANIC CORROSION BEHAVIOR

The existence of contact areas between 356 aluminum and a dissimilar metal or alloy in the Materials Testing Reactor warranted an investigation into the galvanic corrosion behavior of the aluminum alloy. At the time of this corrosion study, other alloys under consideration for use in the reactor were 43 aluminum casting alloy, extruded beryllium, and 347 stainless steel. The use of 43 aluminum has since been eliminated but data will be included in this report for 356 aluminum-43 aluminum contact couples.

For corrosion tests, the 356 aluminum was coupled directly to each of the above metals. The bimetallic couple was secured by means of a nut and bolt passing through the centers of the test specimens. The nut and bolt were machined from a metal common to one of the metals in the couple; i.e., 2S aluminum nuts and bolts were used for 356 aluminum-2S aluminum couples; 43 aluminum nuts and bolts were used for 356 aluminum-43 aluminum couples; 356 aluminum nuts and bolts for 356 aluminum-extruded beryllium couples, and 347 stainless steel nuts and bolts for 356 aluminum-347 stainless steel galvanic couples.

The method of testing the bimetallic couples was similar to the method used for mono-metal tests. Stagnant couple tests consisted of suspending the specimen by means of a glass hook into the corrosion medium. Dynamic couple tests were conducted by fastening the specimens to the end of a long shaft attached to an electric motor. The shaft

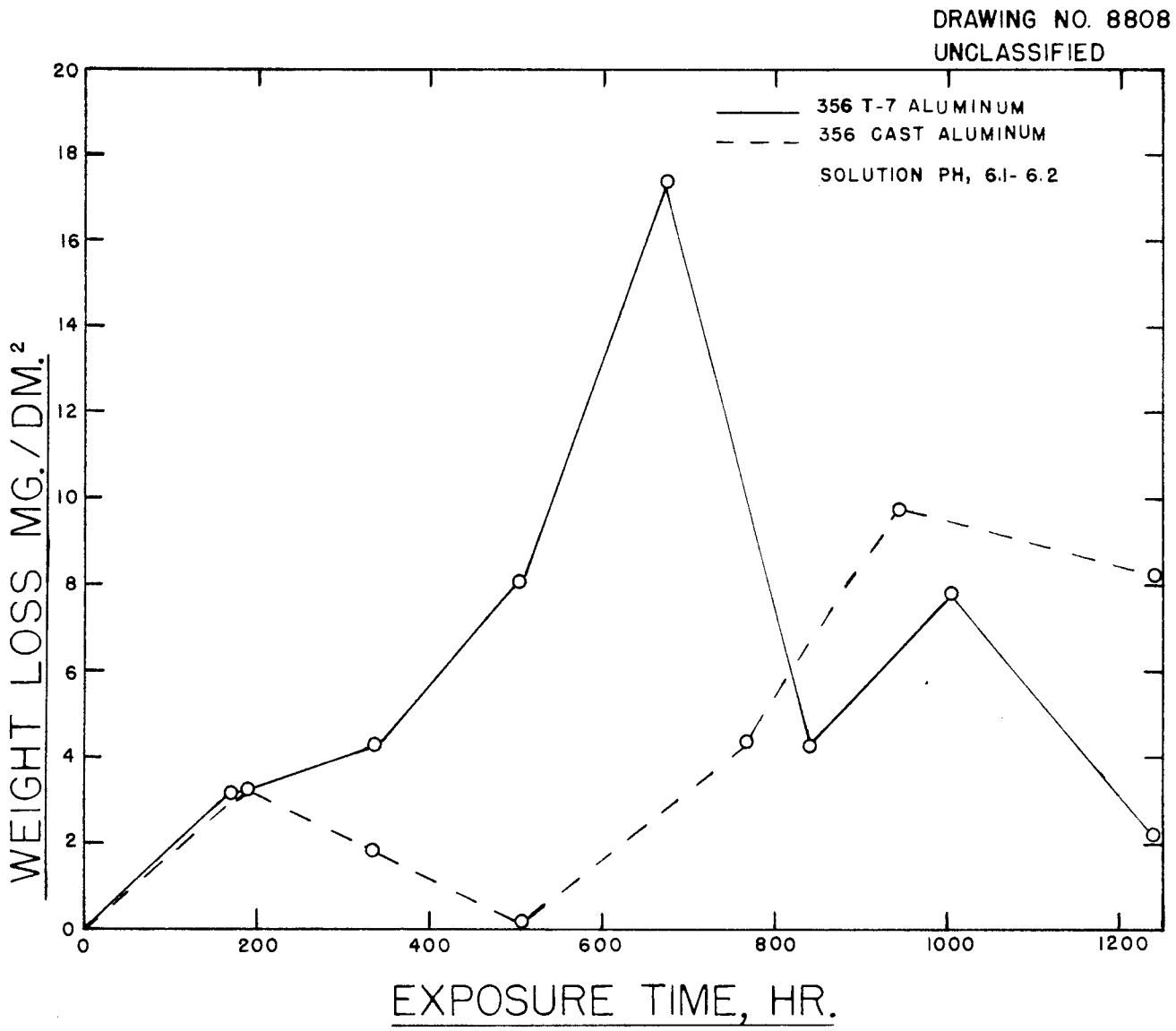

FIG. 10 A COMPARISON OF THE STAGNANT CORROSION BETWEEN CAST AND T-7 356 ALUMINUM IN 0.0005 M HYDROGEN PEROXIDE AT 85°C

8.0 GALVANIC CORROSION BEHAVIOR (CONT'D)

was constructed of the same material as one of the samples in the galvanic couple.

Test exposures were made in demineralized water containing 0.0005M and 0.005M hydrogen peroxide concentrations. All tests were operated at a temperature of 85°C and the duration of each test was 1008 hours.

8.1 2S Aluminum

Stagnant corrosion tests were conducted with 356 aluminum coupled to 2S aluminum exposed to deaerated water, 0.0005M and 0.005M hydrogen peroxide, and 0.0005M hydrogen peroxide containing 10 ppm of sodium chromate as a corrosion inhibitor. These data are included in Tables XXV, XXVI, and XXVII.

In deaerated water, 356 aluminum was preferentially attacked in all cases. The initial corrosion attack was 0.261 mil/month for 168 hours; for 1008 hours exposure, the equivalent thickness loss of the metal was 0.009 mil/month. The average corrosion rate for 1008 hours was 0.053 mil/month. These corrosion rates are based on the defilmed weight losses on the specimens. All specimens, 356 and 2S aluminum, showed a weight gain as removed from the test medium. Corrosion attack on the 2S aluminum was mild; the average corrosion rate was 0.010 mil/month. Figure 11 shows a plot of weight losses for uncoupled 356 aluminum and 356 aluminum coupled to 2S aluminum for similar exposure conditions. It was observed that the initial weight losses on the coupled 356 aluminum were much greater in magnitude than the initial weight losses on the uncoupled aluminum. After an exposure of 300 hours, the weight losses on the coupled 356 aluminum were less in magnitude than on the uncoupled aluminum alloy. Pitting attack was evident on the coupled 356 aluminum and was located almost entirely on the area in immediate contact with the 2S aluminum. The maximum number of pits per sq cm encountered during the 1008 hours exposure was 4.3. The maximum pit depth observed was 11.6 mils. The average pit depth was 8.2 mils. Pitting attack on the 2S aluminum specimens was of a minor nature; a maximum pit depth of 1.1 mils was recorded.

A summation of the data for 356 aluminum coupled to 2S aluminum in deaerated water at 85°C results in the following observations:

1) The corrosion of coupled 356 aluminum is of the same order of magnitude as the corrosion of uncoupled 356 aluminum with the exception that the initial corrosion attack on the former is greater.

[redacted]

TABLE XXV

THE STAGNANT CORROSION OF 356 ALUMINUM-2S ALUMINUM COUPLES IN DEAERATED, DEMINERALIZED WATER AT 85°C

Mat'l	Solution pH	Exposure hr.	Area, cm^2	Pits per Cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
356	6.0	168	14.74	1.0	8.0	28	15.62	41.35	0.261
2S	6.0	168	17.97	neg.	neg.	neg.	17.79	5.01	0.031
356	6.0	336	14.87	3.6	9.0	60	9.40	7.39	0.023
2S	6.0	336	19.80	0.2	1.8	20	13.14	3.54	0.015
356	6.0	504	15.05	4.3	8.0	40	13.95	3.99	0.008
2S	6.0	504	19.67	neg.	neg.	neg.	17.80	0.51	0.002
356	6.1	672	14.82	1.2	11.6	40	17.54	1.35	0.002
2S	6.1	672	19.49	neg.	neg.	neg.	16.41	neg.	neg.
356	5.9	840	14.10	3.7	8.0	100	12.77	11.35	0.014
2S	5.9	840	19.76	1.1	3.6	20	22.77	5.06	0.006
356	6.1	1008	14.97	2.9	4.8	40	18.69	8.68	0.009
2S	6.1	1008	19.17	0.7	6.4	20	21.40	3.13	0.003

[redacted]

[redacted]

TABLE XXVI

THE STAGNANT CORROSION OF 356 ALUMINUM-2S ALUMINUM COUPLES IN HYDROGEN PEROXIDE SOLUTIONS AT 85°C

Mat'l	Solution pH	Exposure hr.	Area, cm^2	Pits per Cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
356	6.1	1240	15.67	0.3	47.3	20	33.15	8.92	0.008[1]
2S	6.1	1240	15.67	neg.	neg.	neg.	31.25	3.19	0.003
356	6.1	1240	15.67	neg.	neg.	neg.	34.45	neg.	neg.[1]
2S	6.1	1240	15.67	neg.	neg.	neg.	31.90	neg.	neg.
356	6.1	168	14.15	1.8	3.2	60	26.15	16.95	0.106[2]
2S	6.1	168	19.70	6.0	2.4	20	25.90	13.72	0.084
356	6.1	336	14.15	1.0	11.2	80	19.08	23.30	0.074[2]
2S	6.1	336	20.31	3.6	2.8	20	36.92	5.92	0.018
356	6.1	504	14.15	1.9	11.6	20	-231.00[3]	262.00	0.522[2]
2S	6.1	504	20.52	1.2	4.4	40	32.65	2.44	0.005
356	6.1	672	14.15	1.8	7.6	40	50.80	26.13	0.041[2]
2S	6.1	672	20.16	neg.	neg.	neg.	70.45	8.93	0.014
356	6.1	840	14.15	2.3	17.2	40	30.35	21.88	0.027[2]
2S	6.1	840	19.49	neg.	neg.	neg.	47.15	neg.	neg.
356	6.1	1008	14.15	1.2	10.8	60	29.78	22.60	0.024[2]
2S	6.1	1008	19.92	0.6	4.0	60	45.15	2.04	0.002

[1] Test solution was 0.0005M hydrogen peroxide
[2] Test solution was 0.005M hydrogen peroxide
[3] Specimen showed a weight loss as removed from the test solution

[redacted]

[redacted]

TABLE XXVII

THE STAGNANT CORROSION OF 356 ALUMINUM-2S ALUMINUM COUPLES IN 0.0005M HYDROGEN PEROXIDE SOLUTION AT 85°C CONTAINING 10 PPM. OF SODIUM CHROMATE

Mat'l	Solution pH	Exposure hr.	Area, cm^2	Pits per Cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
356	6.1	168	15.87	1.0	1.6	40	21.41	6.30	0.039
2S	6.1	168	20.08	1.2	1.6	10	15.94	0.49	0.003
356	6.1	336	15.87	0.8	2.0	20	27.10	17.63	0.056
2S	6.1	336	20.21	0.2	1.2	20	14.35	8.91	0.027
356	6.1	504	15.36	4.4	6.4	30	29.32	0.65	0.001
2S	6.1	504	20.08	neg.	neg.	neg.	35.30	neg.	neg.
356	6.1	672	15.87	0.7	3.4	40	-10.08[1]	30.87	0.049
2S	6.1	672	20.21	0.2	7.2	20	6.44	15.84	0.024
356	6.1	840	15.76	0.4	2.4	20	29.18	20.92	0.026
2S	6.1	840	20.08	0.2	1.2	20	53.75	4.98	0.006
356	6.1	1008	15.77	2.3	24.0	40	45.65	6.98	0.007
2S	6.1	1008	20.21	0.4	4.8	24	52.95	3.96	0.004

[1] Specimen showed a weight loss as removed from the test solution.

[redacted]

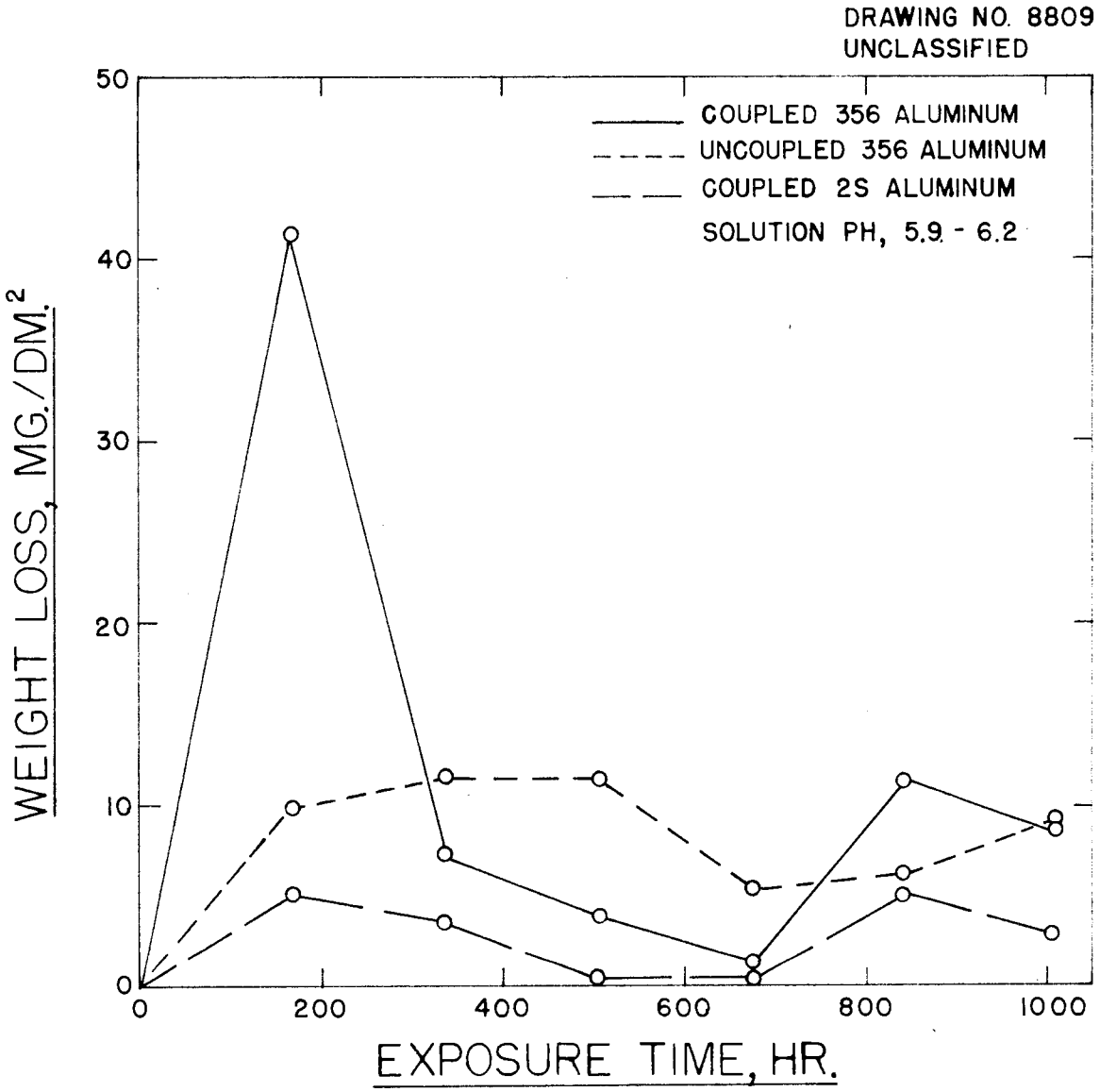

FIG. 11 A COMPARISON OF THE CORROSION OF UNCOUPLED 356 ALUMINUM WITH 356 ALUMINUM COUPLED TO 2S ALUMINUM IN DEAERATED WATER AT 85° C

8.1 2S Aluminum (Cont'd)

2) The frequency of localized attack is greater on coupled 356 aluminum than on uncoupled 356 aluminum. The greatest pit distribution occurs on the contact area.

3) The average depth of pits was greater on coupled 356 aluminum than on the uncoupled material.

Corrosion data for 356 aluminum-2S aluminum couples exposed to hydrogen peroxide solutions are included in Table XXVI. With the exception of one 356 aluminum specimen, all test samples exhibited a weight gain as removed from the test media. Again, the 356 aluminum was preferentially attacked. In 0.0005M hydrogen peroxide, the average corrosion rate for the 356 aluminum over 1240 hours exposure was 0.004 mil/month. A maximum pit depth of 47.3 mils was observed on one specimen, but generally localized attack was very slight. Corrosion attack on the aluminum was more pronounced in the 0.005M hydrogen peroxide solutions. Except for one sample exposed for 504 hours, the average defilmed weight loss was 31.24 mg./dm^2 The equivalent loss in thickness for 1008 hours exposure was 0.024 mil/month. Figure 12 shows a comparison of the defilmed weight losses for 356 aluminum coupled to 2S aluminum and uncoupled 356 aluminum in 0.005M hydrogen peroxide solutions. The acceleration of corrosion attack on the coupled aluminum is clearly illustrated. The maximum pit depth encountered on 356 aluminum specimens in 0.005M peroxide was 17.2 mils; the maximum pit count (pits/sq cm) was 2.3.

Summarizing these stagnant corrosion data for 356 aluminum coupled to 2S aluminum in hydrogen peroxide solutions, the following observations were made:

1) The corrosion of 356 aluminum in 0.0005M hydrogen was nearly the same in magnitude as the corrosion of uncoupled 356 aluminum in similar solutions.

2) The corrosion of 356 aluminum in 0.005M hydrogen peroxide was greatly accelerated by contact with 2S aluminum as compared to uncoupled 356 aluminum in 0.005M hydrogen peroxide.

3) Pit distribution on coupled 356 aluminum in 0.005M hydrogen peroxide was greater than on uncoupled 356 aluminum in 0.005M peroxide.

The results of corrosion tests with 356 aluminum-2S aluminum couples in 0.0005M hydrogen peroxide solutions containing 10 ppm of sodium chromate are shown in Table XXVII. In most cases, both the

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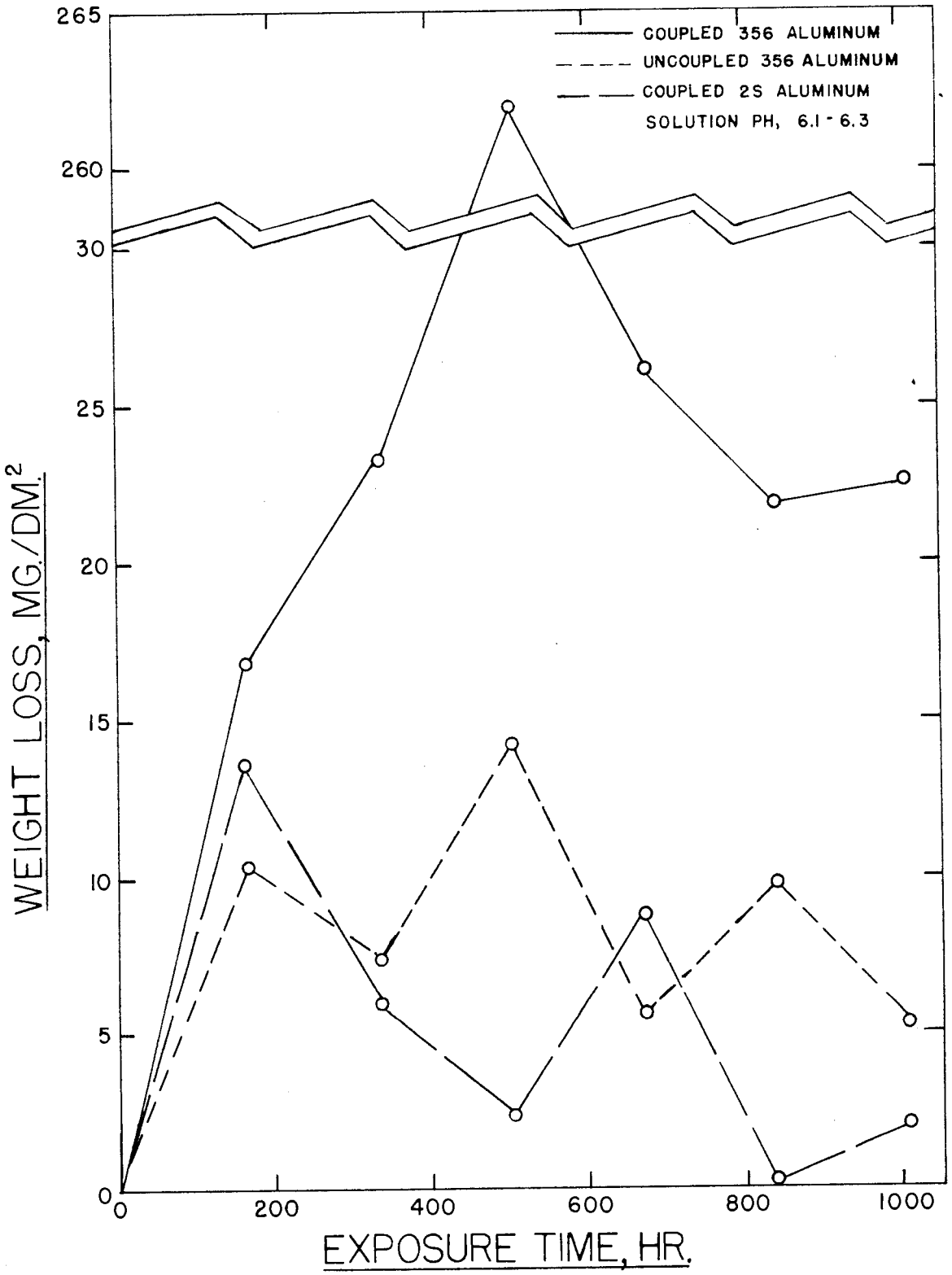

FIG. 12 A COMPARISON OF THE CORROSION OF UNCOUPLED 356 ALUMINUM WITH 356 ALUMINUM COUPLED TO 2S ALUMINUM IN 0.005 M HYDROGEN PEROXIDE AT 85°C

8.1 2S Aluminum (Cont'd)

356 and 2S aluminum specimens gained in weight during the exposure periods. Defilmed weight losses indicated that 356 aluminum was preferentially attacked in contact with 2S aluminum. The greatest defilmed weight loss, 30.87 mg/dm^2, was observed on a specimen exposed for 672 hours. The corrosion attack decreased rapidly after this time. The presence of 10 ppm of sodium chromate was not completely effective for eliminating localized corrosion attack on the 356 aluminum. A maximum pit depth of 24 mils was observed after 1008 hours of exposure; the maximum number of pits per sq cm was observed on a specimen exposed for 504 hours.

Figure 13 shows a comparison of weight losses for coupled 356 aluminum and uncoupled 356 aluminum in 0.0005M hydrogen peroxide containing 10 ppm of sodium chromate. Weight losses were much greater on the coupled aluminum alloy. Specimens exposed for 1008 hours however showed a weight loss of 6.98 mg/dm^2 as compared to a weight loss of 12.75 mg/dm^2 on the uncoupled aluminum

The conclusions drawn from the results of these tests indicate that in 0.0005M hydrogen peroxide containing 10 ppm of sodium chromate,

1) Little or no beneficial effects on the corrosion resistance of coupled 356 aluminum are obtained with sodium chromate as a corrosion inhibitor.

2) There was no apparent reduction in the intensity or frequency of pitting attack on coupled 356 aluminum in the presence of sodium chromate.

A summary of the galvanic corrosion of 356 aluminum coupled to 2S aluminum in various stagnant test media is shown graphically in Figure 14. The maximum weight loss, maximum pit depth, maximum pit diameter, and maximum pit count values are presented for 356 aluminum exposed to deaerated water, 0.005M hydrogen peroxide, and 0.0005M hydrogen peroxide containing 10 ppm of sodium chromate as a corrosion inhibitor. The total exposure time of the tests was 1008 hours.

Sodium chromate was partially effective for reducing the weight losses on the specimens but had no beneficial influence on the reduction of the depth of pits. The most severe weight loss was encountered in the 0.005M hydrogen peroxide solutions. This loss was 262 mg/dm^2.

A general observation of these data indicates that the most favorable conditions for minimized galvanic corrosion of 356 aluminum

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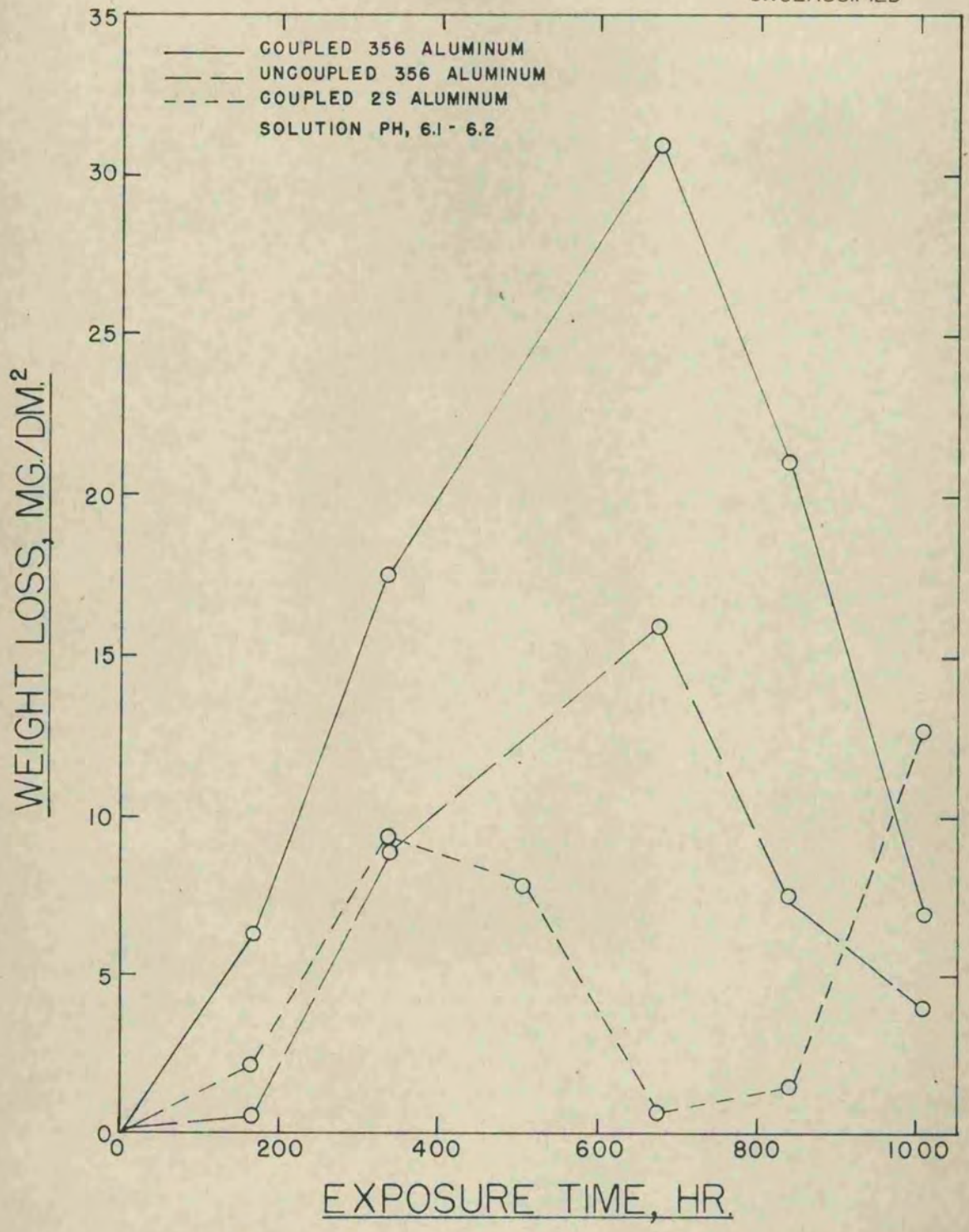

FIG. 13 A COMPARISON OF THE CORROSION OF UNCOUPLED 356 ALUMINUM WITH 356 ALUMINUM COUPLED TO 2S ALUMINUM IN 0.0005 M HYDROGEN PEROXIDE CONTAINING 10PPM. OF SODIUM CHROMATE AT 85° C

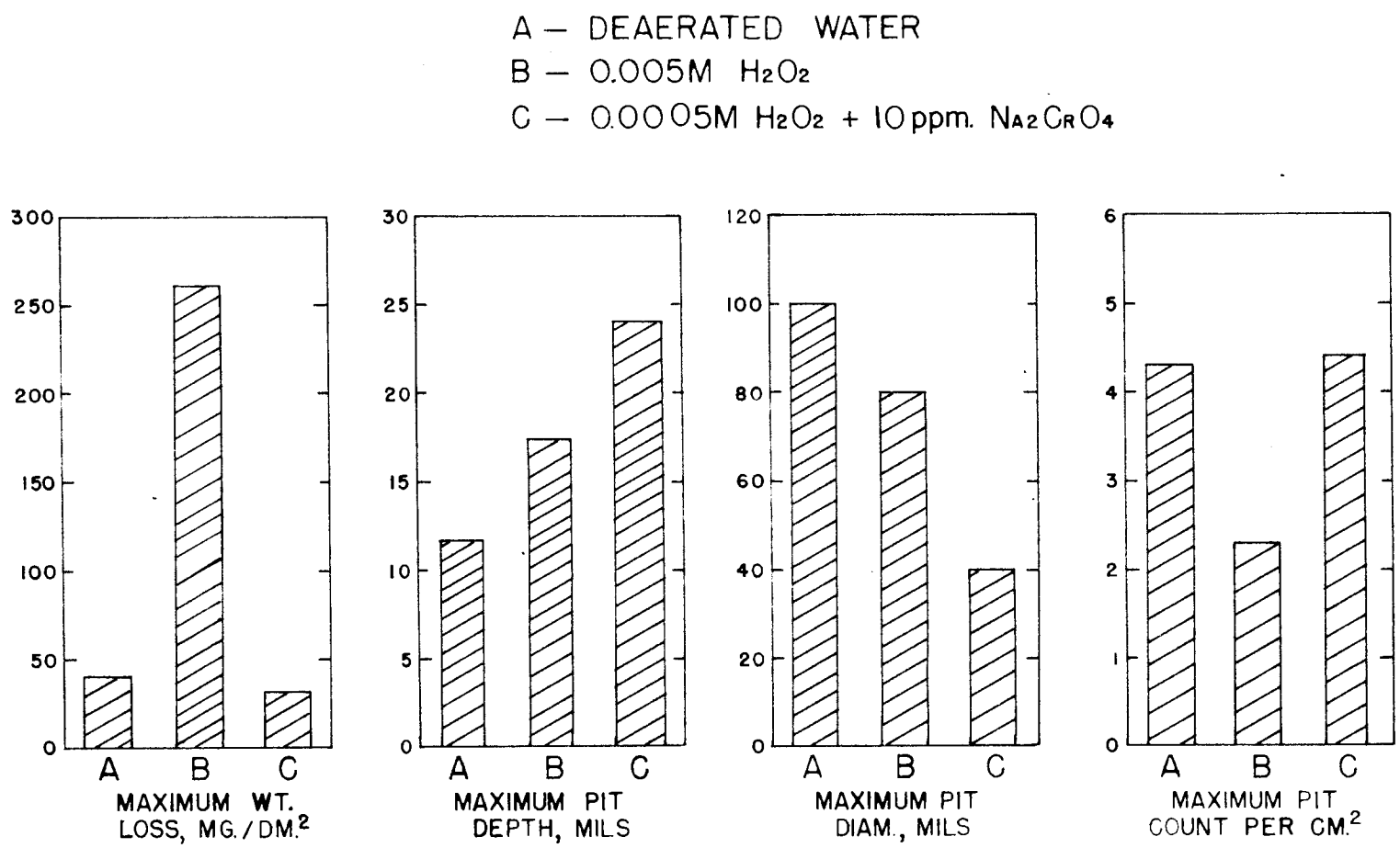

FIG. 14 STAGNANT CORROSION DATA FOR 356 ALUMINUM COUPLED TO 2S ALUMINUM IN VARIOUS TEST MEDIA AT 85°C FOR 1008 HOURS

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8.1 2S Aluminum (Cont'd)

when coupled to 2S aluminum are those offered by the deaerated water. The maximum weight loss and pit depth are low as compared to values obtained in the other solutions. The maximum pit diameter and pit count were high in value, however, as compared to the results in the other test solutions.

8.2 43 Aluminum Casting Alloy

A few stagnant corrosion tests with 356 aluminum coupled to 43 aluminum were conducted. These tests were made in 0.0005M and 0.005M hydrogen peroxide solutions at 85°C for 1240 hours. The corrosion results are included in Table XXVIII.

As removed from the test solutions, all samples exhibited a gain in weight due to the formation of the protective film and the accumulation of corrosion products. The "as cast" sample of 356 aluminum showed slightly better corrosion resistance than the heat treated 356 alloy in both peroxide solutions. In general, the 356 aluminum alloys were preferentially attacked.

The frequency of pits was found to be greater on the 356 aluminum specimens and in most cases, the pit intensity was more severe. An exception occurred with the heat treated 356 aluminum coupled to 43 aluminum in 0.0005M hydrogen peroxide. In this case a maximum pit depth of 28 mils was observed on the 43 alloy; the maximum pit depth on the 356 aluminum was 2.8 mils. The corrosion resistance of both the cast and T-7 forms of 356 aluminum was better in the lower peroxide concentrations, 0.0005M.

8.3 Extruded Beryllium

Corrosion test data for 356 aluminum-extruded beryllium couples are included in Tables XXIX, XXX, and XXXI. Tests were conducted under stagnant and dynamic conditions in 0.0005M and 0.005M hydrogen peroxide solutions and 0.0005M hydrogen peroxide containing 10 ppm of sodium chromate.

The beryllium metal used for these tests had exhibited good corrosion resistance to simulated reactor water in previous tests.

Table XXIX shows the effect of velocity on the galvanic corrosion of the 356 aluminum in deaerated water. Under both stagnant and dynamic conditions, 356 aluminum was preferentially attacked. The corrosion rates of the aluminum and the beryllium increased slightly as the specimens were rotated at speeds of 6-8 feet/second in the water. At the same time a decrease in the depths and diameters of pits was observed. It was noticed that on the stagnant 356

[redacted]

TABLE XXVIII

THE STAGNANT CORROSION OF 356 ALUMINUM-43 ALUMINUM COUPLES IN HYDROGEN PEROXIDE SOLUTION AT 85°C FOR 1240 HOURS

Mat'l	Solution pH	Exposure hr.	Area, cm^2	Pits per Cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
356[1]	6.1	0.0005M	15.67	1.2	12.0	60	31.90	0.64	< 0.001
43	6.1	0.0005M	15.67	neg.	neg.	neg.	31.90	2.55	0.002
356[2]	6.1	0.0005M	15.67	1.5	2.8	8	28.70	10.85	0.009
43	6.1	0.0005M	15.34	1.2	28.0	20	41.65	8.46	0.007
356[1]	6.1	0.005M	15.67	2.0	12.0	40	35.72	8.28	0.007
43	6.1	0.005M	15.34	neg.	neg.	neg.	47.55	neg.	neg.
356[2]	6.1	0.005M	15.67	0.8	20.0	44	63.15	27.25	0.023
43	6.1	0.005M	15.67	0.7	14.4	24	63.15	38.30	0.003

[1] As cast 356 aluminum alloy

[2] 356T-7 aluminum alloy

[redacted]

[redacted]

TABLE XXIX

THE EFFECT OF VELOCITY ON THE CORROSION OF 356 ALUMINUM - EXTRUDED BERYLLIUM COUPLES OF DEAERATED DEMINERALIZED WATER AT 85°C

Mat'l	Solution pH	Exposure hr.	Area, cm^2	Pits per Cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
356[1]	6.2	1008	14.40	1.7	18.4	80	6.25	43.05	0.045
Be	6.2	1008	12.67	1.8	10.8	40	-4.73[3]	7.88	0.012
356[2]	6.2	1008	13.99	1.8	13.6	50	-26.45[3]	55.75	0.059
Be	6.2	1008	10.47	1.0	5.2	20	-6.68[3]	9.54	0.015

[1] Stagnant corrosion test

[2] Dynamic corrosion test in which specimens rotated 8 feet/second

[3] Specimen showed a weight loss as removed from the test solution

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TABLE XXX

THE STAGNANT AND DYNAMIC CORROSION OF 356 ALUMINUM - EXTRUDED BERYLLIUM COUPLES IN 0.0005M HYDROGEN PEROXIDE AT 85°C

Mat'l	Solution pH	Exposure hr.	Area, cm^2	Pits per Cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
356[1]	6.2	1008	13.99	0.2	12.8	20	21.03	17.16	0.019
Be	6.2	1008	12.67	1.2	5.2	10	-18.15	24.45	0.037
356[1]	6.1	1240	15.47	0.8	24.8	80	48.50	16.81	0.014
Be	6.1	1240	21.54	3.5	6.4	30	-1.86	18.56	0.023
356[2]	6.1	1240	15.67	neg.	neg.	neg.	26.15	neg.	neg.
Be	6.1	1240	25.26	2.0	2.4	28	8.32	4.36	0.005
356[3]	6.2	1008	14.04	neg.	neg.	neg.	14.25	13.53	0.014
Be	6.2	1008	12.67	0.9	2.7	10	-15.80	15.77	0.024

[1] Stagnant test, 356T-7 aluminum.

[2] Stagnant test, as cast 356 aluminum.

[3] Dynamic test, 356T-7 aluminum, specimen velocity 8 ft./sec.

[redacted]

[redacted]

TABLE XXXI

THE STAGNANT AND DYNAMIC CORROSION OF 356 ALUMINUM - EXTRUDED BERYLLIUM COUPLES IN 0.005M HYDROGEN PEROXIDE AT 85°C

Mat'l	Solution pH	Exposure hr.	Area, cm^2	Pits per Cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
356[1]	6.2	1008	14.71	1.4	12.4	60	25.85	10.20	0.011
Be	6.2	1008	12.67	2.5	1.7	20	-7.10	18.95	0.029
356[1]	6.1	1240	15.70	0.8	20.0	30	70.65	7.64	0.007
Be	6.1	1240	23.68	8.9	4.8	20	-14.35	40.50	0.050
356[2]	6.2	1240	15.67	0.5	6.4	32	67.50	8.28	0.008
Be	6.2	1240	20.24	8.8	2.4	180[4]	3.95	45.85	0.057
356[3]	6.2	1008	15.23	2.5	4.8	20	28.25	27.60	0.029
Be	6.2	1008	12.32	0.6	2.2	10	-12.17	19.47	0.029

[1] Stagnant test, 356T-7 aluminum.

[2] Stagnant test, as cast 356 aluminum.

[3] Dynamic test, 356T-7 aluminum, specimen velocity 8 ft/sec.

[4] This figure represents the diameter of a cluster of pits.

[redacted]

8.3 Extruded Beryllium (Cont'd)

specimen, 95% of the total number of pits were located on the area in immediate contact with the beryllium; on the dynamic 356 specimen, no pits were observed on this contact area. In both tests, a weight loss on the beryllium specimens occurred as removed from the test solutions; a weight gain was observed on the stagnant 356 aluminum specimen, but a weight loss was reported on the dynamic aluminum specimen.

Cast and heat treated 356 aluminum specimens were coupled to extruded beryllium and exposed to 0.0005M hydrogen peroxide solutions. In the presence of the peroxide, the beryllium was preferentially attacked. The corrosion resistance of the T-7 aluminum was essentially the same under stagnant and dynamic tests. There was a tendency, however, for pits to penetrate more deeply on the stagnant specimen. The corrosion rate for the cast 356 aluminum was negligible and no pits were observed under stagnant test conditions. Most of the beryllium specimens showed a weight loss upon their removal from the test solutions; all of the 356 aluminum specimens exhibited weight gains.

Table XXXI shows stagnant and dynamic corrosion data for 356 aluminum-extruded beryllium couples exposed to 0.005M hydrogen peroxide solutions. In the stagnant tests, the corrosion resistance of the cast aluminum and the heat treated aluminum was nearly identical except that deeper pits were encountered on the T-7 material. The beryllium metal in these couple tests was attacked preferentially and the magnitude of this attack was greater on the metal coupled to the cast 356 aluminum.

In the dynamic couple test, the corrosion rate for 356 T-7 aluminum was nearly tripled as compared to the rate obtained for stagnant conditions. Pits on this specimen were not as deep as those observed on the stagnant test specimen.

In this series of tests, the 356 aluminum specimens showed a gain in weight as they were taken from the test solutions. The beryllium specimens exhibited weight losses as removed from the test media with the exception of the beryllium sample coupled to cast 356 aluminum in a stagnant corrosion test. This specimen showed a weight gain.

The effect of adding sodium chromate to the test media for inhibition of corrosion attack was studied. These data are included in Table XXXII for 356 aluminum-extruded beryllium couples exposed to stagnant and dynamic conditions. The concentration of sodium chromate used for these tests was 5 ppm. In several tests, the water pH was increased from 6.1 to 7.7 to further determine the effectiveness of this inhibitor in slightly basic waters.

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TABLE XXXII

THE STAGNANT AND DYNAMIC CORROSION OF 356 ALUMINUM-EXTRUDED BERYLLIUM COUPLES IN 0.0005M HYDROGEN PEROXIDE CONTAINING 5 PPM. OF SODIUM CHROMATE AT 85°C

Mat'l	Solution pH	Exposure hr.	Area, cm^2	Pits per cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
356[1]	6.1	1008	15.56	0.6	6.8	20	21.85	1.28	0.001
Be	6.1	1008	10.47	1.8	2.8	10	- 8.59	13.37	0.020
356[1]	7.7	1008	14.04	6.3	3.2	20	14.24	189.50	0.199
Be	7.7	1008	12.67	3.4	7.6	10	- 2.37	1.58	0.002
356[2]	6.1	1008	13.99	1.0	2.2	40	6.72	35.00	0.037
Be	6.1	1008	10.47	1.2	8.4	20	-10.52	20.08	0.030
356[2]	7.7	1008	13.99	neg.	neg.	neg.	3.57	437.50	0.460
Be	7.7	1008	12.27	0.7	10.0	60	- 0.81	1.63	0.003

[1] Stagnant test

[2] Dynamic test; specimen velocity, 6-8 ft./sec.

[redacted]

8.3 Extruded Beryllium (Cont'd)

It was observed that sodium chromate was effective for reducing the corrosion attack on 356 aluminum coupled to beryllium under stagnant conditions. A corrosion rate of 0.001 mil/month was reported for the aluminum; the equivalent thickness loss on the beryllium was 0.020 mil/month. A similar reduction in pitting frequency and intensity was observed also. There was no apparent effect by the chromate on the corrosion rates of these metals in the dynamic test conducted. When the water pH was increased to 7.7, the resultant corrosion attack on the 356 aluminum was increased markedly. Corrosion rates of 0.199 mil/month were observed for stagnant conditions and 0.460 mil/month for dynamic exposure. In both tests, the corrosion of beryllium was 0.002-0.003 mil/month, a marked decrease over rates encountered in water having a pH of 6.1.

A summation of all stagnant and dynamic corrosion data with 356 aluminum(T-7)-extruded beryllium couples is shown in Figure 15. Maximum weight losses, maximum pit depths, maximum pit diameters, and the maximum number of pits per sq cm are included in this graph.

The best overall performance of 356 aluminum was obtained in 0.0005M hydrogen peroxide solutions. The next best corrosion resistance of the alloy was observed in 0.0005M hydrogen peroxide solutions containing 5 ppm of sodium chromate. In general, the most severe corrosion attack was encountered in deaerated water having a solution pH of 6.2 Greater weight losses, pit depths, and pit diameters were encountered on these specimens in greater magnitude than on specimens exposed to the other test media. These data tend to indicate the need for oxygen availability in small concentrations for the formation and repair of a protective film on the aluminum specimens. When the available oxygen supply exceeds an apparent critical concentration, localized corrosion attack on the aluminum was greatly stimulated.

8.4 347 Stainless Steel

The last in the series of galvanic corrosion studies was made with 356 aluminum coupled to Type 347 stainless steel. Since the position of nickel-chromium steels on the electromotive series of metals and alloys[1] is widely separated from that of the aluminum alloys, it would be expected that the less noble metals, the aluminum alloys, would undergo more severe corrosion attack than for instance, if these alloys were coupled to beryllium. In other words, the electrolytic potential between 347 stainless steel and 356 aluminum is much

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[1] Materials and Methods, December 1946, page 1501.

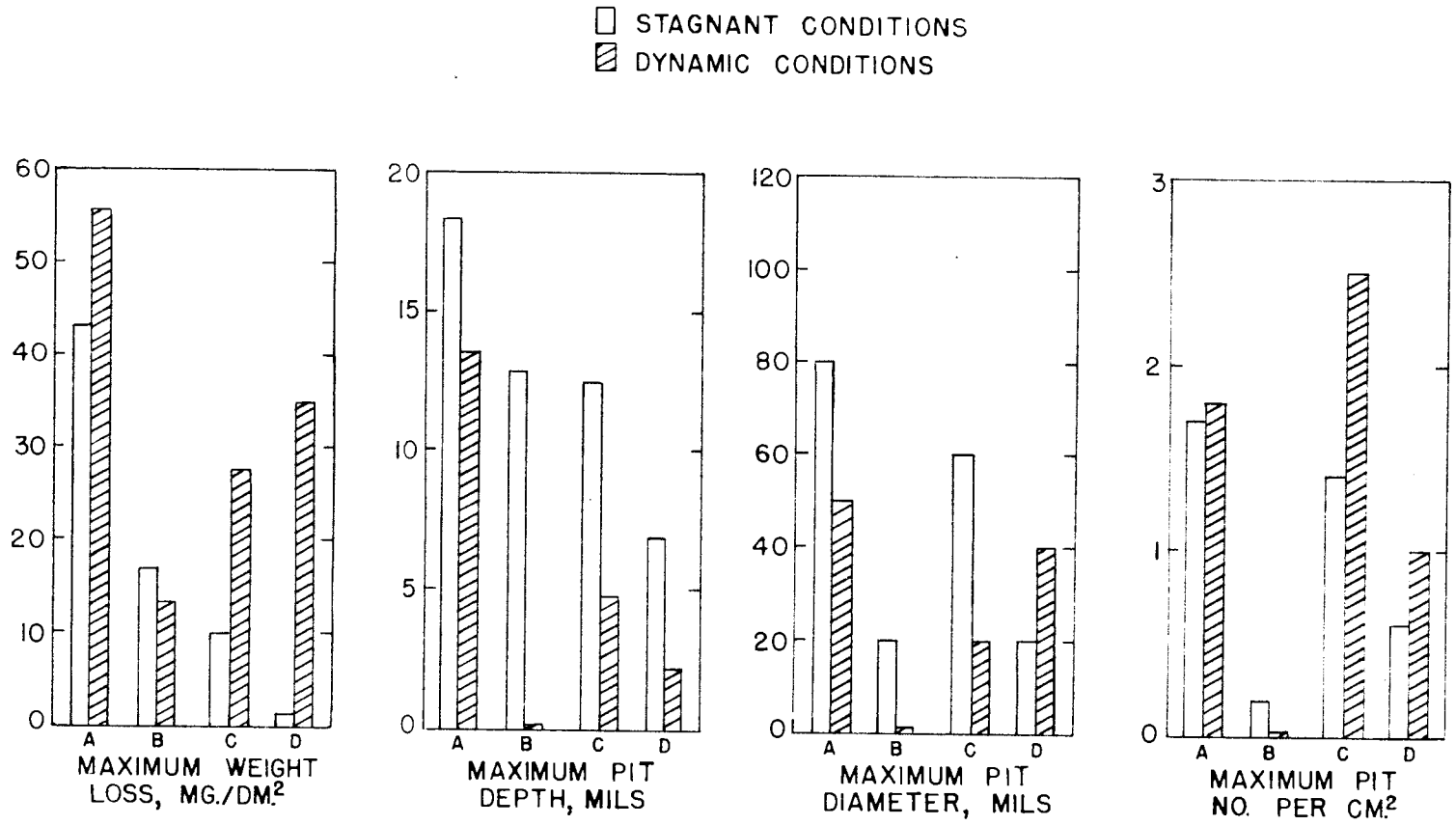

FIG. 15 A COMPARISON OF THE CORROSION ATTACK ON 356T-7 ALUMINUM COUPLED TO EXTRUDED BERYLLIUM IN VARIOUS MEDIA AT 85°C FOR 1008 HOURS

A DEAERATED DEMINERALIZED WATER, PH 6.2
B 0.0005M HYDROGEN PEROXIDE, PH 6.1 - 6.2
C 0.005M HYDROGEN PEROXIDE, PH 6.1 - 6.2
D 0.0005M HYDROGEN PEROXIDE + 5PPM. Na_2CrO_4, PH 6.1

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8.4 347 Stainless Steel (Cont'd)

greater than the potential between beryllium and 356 aluminum. The greater the difference of potential between two dissimilar metals, the greater becomes the susceptibility of galvanic corrosion attack on the less noble metal.

In the design of the Materials Testing Reactor, an area of dissimilar metal contact of this type exists on the fuel rod assemblies where a 347 stainless steel positioning ring is fitted onto the 356 aluminum end box. A favorable advantage exists, however, from a corrosion viewpoint, in that the ratio of anodic surface (356 aluminum) to cathodic surface (347 stainless steel) is fairly great. In such cases, the intensification of corrosion attack on the anodic member of a couple is largely controlled by the ratio of the anodic to cathodic surface areas. A small anode-to-cathode area ratio would result in severe intensification of corrosion attack on the former.

The 356 aluminum-347 stainless steel couple was first studied in deaerated, demineralized water at 85°C. These results are included in Table XXXIII. In all instances, the 356 aluminum was attacked preferentially. Corrosion attack on the 347 stainless steel was negligible. The corrosion rates on the 356 aluminum were slightly high initially, but after an exposure of 1008 hours, an equivalent thickness loss of 0.012 mil/month was observed. This figure compares very favorably with the corrosion rate of uncoupled 356 aluminum in stagnant, deaerated water. Pit depths, in general, were much deeper on the couple tests than on the uncoupled specimens. All of the aluminum specimens showed a gain in weight as they were removed from the test medium.

Figure 16 shows a plot of weight losses and maximum pit depths for 356 aluminum coupled to 347 stainless steel in deaerated water at 85°C. These data are plotted as a function of exposure time. The weight loss on the aluminum alloy progressed rapidly for 336 hours to a value of 10 mg/dm^2. A gradual decrease in the corrosion attack followed for 336 hours after which there appeared a sudden increase in attack during the ensuing 168 hours. The maximum weight loss for the entire test occurred on a specimen exposed for 840 hours. This value was 13.05 mg/dm^2. The deepest pit observed on the six specimens was 18 mils and appeared on the specimen exposed for 168 hours. As noted in Table XXXIII, all aluminum specimens exhibited weight gains as removed from the test medium.

Tables XXXIV and XXXV contain stagnant corrosion data for 356 aluminum-347 stainless steel couples exposed to 0.0005M and 0.005M hydrogen peroxide solutions. These data indicate definitely that as the concentration of hydrogen peroxide is increased from 0.0005M to 0.005M, the galvanic corrosion attack on 356 aluminum is intensified. The aluminum specimens showed weight losses as removed from

[redacted]

TABLE XXXIII

THE STAGNANT CORROSION OF 356 ALUMINUM-347 STAINLESS STEEL COUPLES EXPOSED TO DEAERATED, DEMINERALIZED WATER AT 85°C

Mat'l	Solution pH	Exposure hr.	Area, cm^2	Pits per cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
356	6.2	168	15.11	2.4	18.0	28	16.55	3.97	0.025
347	6.2	168	19.58	neg.	neg.	neg.	1.02	0.51	<0.001
356	6.2	336	15.14	6.7	11.5	60	15.85	9.82	0.031
347	6.2	336	19.58	neg.	neg.	neg.	neg.	neg.	neg.
356	6.1	504	15.14	3.8	3.8	60	14.53	9.24	0.019
347	6.1	504	19.58	neg.	neg.	neg.	neg.	neg.	neg.
356	6.1	672	15.29	3.9	12.7	60	13.81	1.31	0.002
347	6.1	672	19.58	neg.	neg.	neg.	neg.	neg.	neg.
356	6.2	840	13.79	4.9	5.6	80	9.42	13.05	0.017
347	6.2	840	19.58	neg.	neg.	neg.	neg.	neg.	neg.
356	6.1	1008	15.49	5.9	12.0	50	10.53	11.63	0.012
347	6.1	1008	19.58	neg.	neg.	neg.	0.51	neg.	neg.

[redacted]

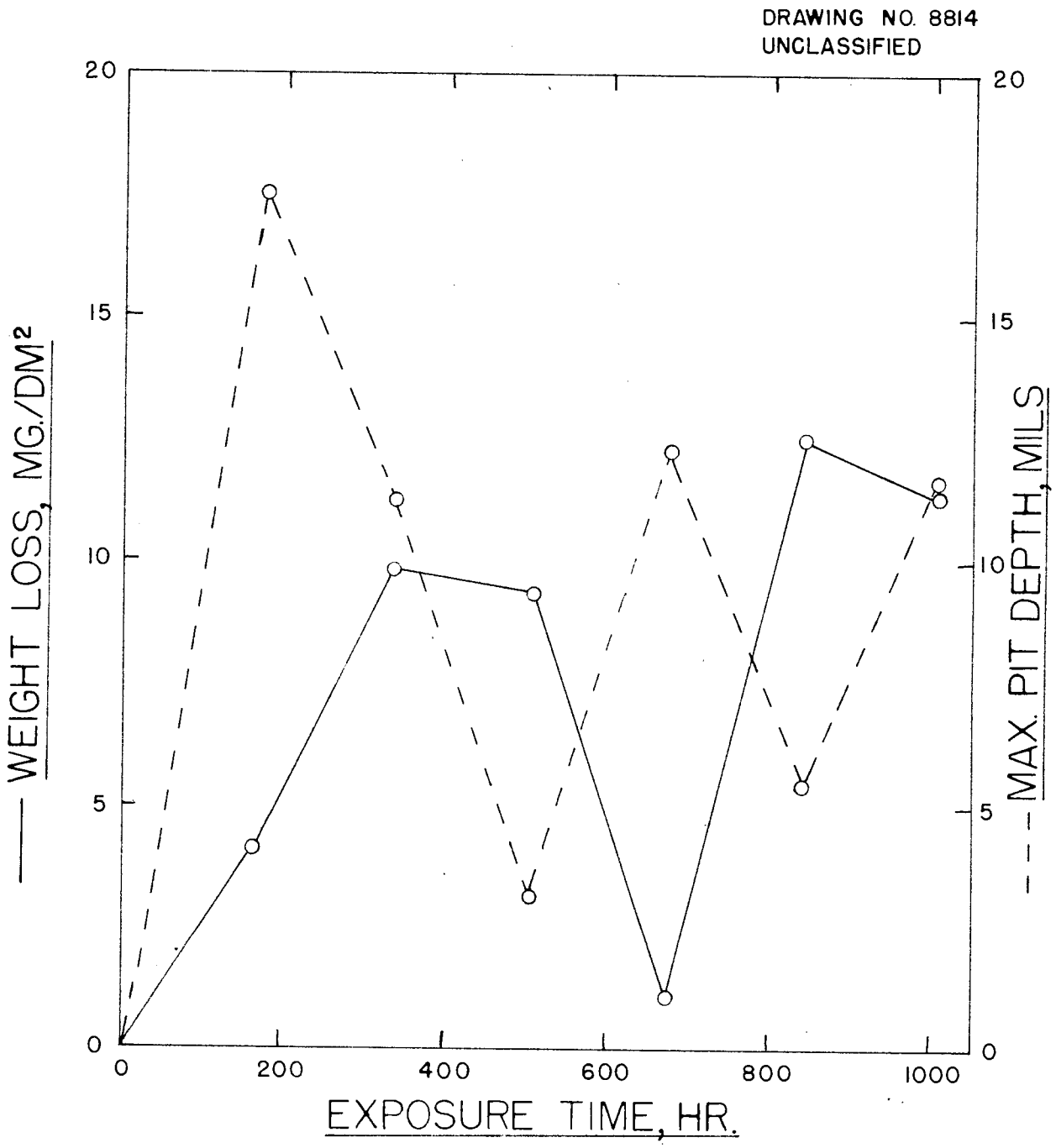

FIG. 16 STAGNANT CORROSION OF 356 ALUMINUM COUPLED TO 347 STAINLESS STEEL IN DEAERATED WATER AT 85°C

[redacted]

TABLE XXIV

THE STAGNANT CORROSION OF 356 ALUMINUM-347 STAINLESS STEEL COUPLES IN 0.0005M HYDROGEN PEROXIDE AT 85°C

Mat'l	Solution pH	Exposure hr.	Area, cm^2	Pits per cm^2	Max. Pit Depth mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
356	6.1	168	15.26	2.6	12.8	60	-15.07	44.5Ø	0.281
347	6.1	168	21.58	neg.	neg.	neg.	2.32	neg.	neg.
356	6.1	336	15.35	5.0	20.0	80	-29.95	87.3Ø	0.277
347	6.1	336	21.58	neg.	neg.	neg.	2.78	neg.	neg.
356	6.1	504	15.76	8.6	19.3	80	-102.80	172.0	0.362
347	6.1	504	21.58	neg.	neg.	neg.	2.32	neg.	neg.
356	6.1	672	15.35	3.3	35.6	100	-126.30	218.0	0.345
347	6.1	672	21.58	neg.	neg.	neg.	7.88	neg.	neg.
356	6.1	840	15.76	5.3	39.6	80	-175.30	306.0	0.385
347	6.1	840	21.58	neg.	neg.	neg.	21.30	neg.	neg.
356	6.1	1008	15.35	7.2	37.6	80	-203.20	364.0	0.382
347	6.1	1008	21.58	neg.	neg.	neg.	25.95	neg.	neg.
356	6.1	1240	15.67	3.6	41.6	100	-89.25	222.5	0.156
347	6.1	1240	21.54	neg.	neg.	neg.	18.10	3.7	0.001

[redacted]

[redacted]

TABLE XXXV

THE STAGNANT CORROSION OF 356 ALUMINUM-347 STAINLESS STEEL COUPLES IN 0.005M HYDROGEN PEROXIDE AT 85°C

Mat'l	Solution pH	Exposure hr.	Area, cm^2	Pits per cm^2	Max. Pit Depth, mils	Max. Pit Dia., mils	Removed Wt. Gain, $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
356	6.2	168	15.22	9.2	18.4	80	-80.75	140.0	0.882
347	6.2	168	21.58	neg.	neg.	neg.	1.85	neg.	neg.
356	6.2	336	15.42	10.8	17.6	80	-92.10	179.7	0.566
347	6.2	336	21.58	neg.	neg.	neg.	9.73	neg.	neg.
356	6.2	504	15.42	16.4	20.0	82	-245.5	364.0	0.766
347	6.2	504	21.58	neg.	neg.	neg.	4.6	neg.	neg.
356	6.2	672	15.12	13.8	18.0	80	-76.7	168.0	0.264
347	6.2	672	21.58	neg.	neg.	neg.	0.9	neg.	neg.
356	6.2	840	15.82	14.5	37.6	80	-226.0	369.3	0.465
347	6.2	840	21.58	9.7	neg.	neg.	neg.	neg.	neg.
356	6.2	1008	15.82	10.1	36.0	78	-270.5	357.0	0.373
347	6.2	1008	21.58	neg.	neg.	neg.	12.1	neg.	neg.
356	6.1	1240	15.67	9.6	20.4	80	-191.5	375.2	0.321
347	6.1	1240	12.08	neg.	neg.	neg.	19.8	4.1	0.001

[redacted]

8.4 347 Stainless Steel (Cont'd)

the test solutions. Pitting attack was extremely severe on these specimens in both types of solutions. The most prolific concentration of pits occurred on the area in immediate contact with the stainless steel.

Figure 17 and 18 show the defilmed weight losses on the 356 aluminum specimens as a function of the exposure time. The maximum pit depths observed are included in these data. In the 0.0005M peroxide solutions, corrosion attack progressed linearly to a maximum weight loss of 364 mg/dm^2 on a specimen exposed for 1008 hours. Corrosion attack on the aluminum specimens exposed to 0.005M peroxide was erratic, but the initial attack was extremely severe. A maximum weight loss of 369 mg/dm^2 was reported after an exposure of 840 hours. Many pits, 36-42 mils in depth, were observed on specimens immersed in both low and high peroxide solutions.

Summarizing, the corrosion characteristics of 356 aluminum coupled to 347 stainless steel are greatly determined by the presence or absence of oxygen in the test media. As the concentration of oxygen increased, the galvanic corrosion of the aluminum was increased drastically under the conditions of the tests. In oxygen-free water, corrosion attack on the aluminum was mild.

The final phase of the study to determine the corrosion behavior of 356 aluminum coupled to 347 stainless steel concerned the use of sodium chromate for inhibition of this type of corrosion attack. Concentrations of 10 ppm of sodium chromate were employed in demineralized water containing 0.005M hydrogen peroxide. These data are included in Table XXXVI.

In the presence of small amounts of hydrogen peroxide at 85°C, the sodium chromate was beneficial for reducing the intensity of galvanic corrosion attack on the aluminum alloy. This beneficial influence is shown by a comparison of the data in Tables XXXIV, XXXV, and XXXVI. The maximum weight loss for 356 aluminum coupled to 347 stainless steel in uninhibited 0.0005M hydrogen peroxide was 364 mg/dm^2; in 0.005M hydrogen peroxide containing no sodium chromate, the maximum defilmed weight loss was 375 mg/dm^2. The maximum weight loss observed on the aluminum specimens exposed to the inhibited 0.005M peroxide solution was 28.65 mg/dm^2. The severity of pitting attack was drastically reduced by the presence of sodium chromate as compared to pitting attack on specimens exposed to uninhibited peroxide solutions.

The beneficial influence of sodium chromate for inhibiting corrosion attack on 356 aluminum is substantiated by the use of Mear's[1]

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[1] R. B. Mears and G. G. Eldredge, Trans. Electro. Chem. Soc., 83, 4, 1942.

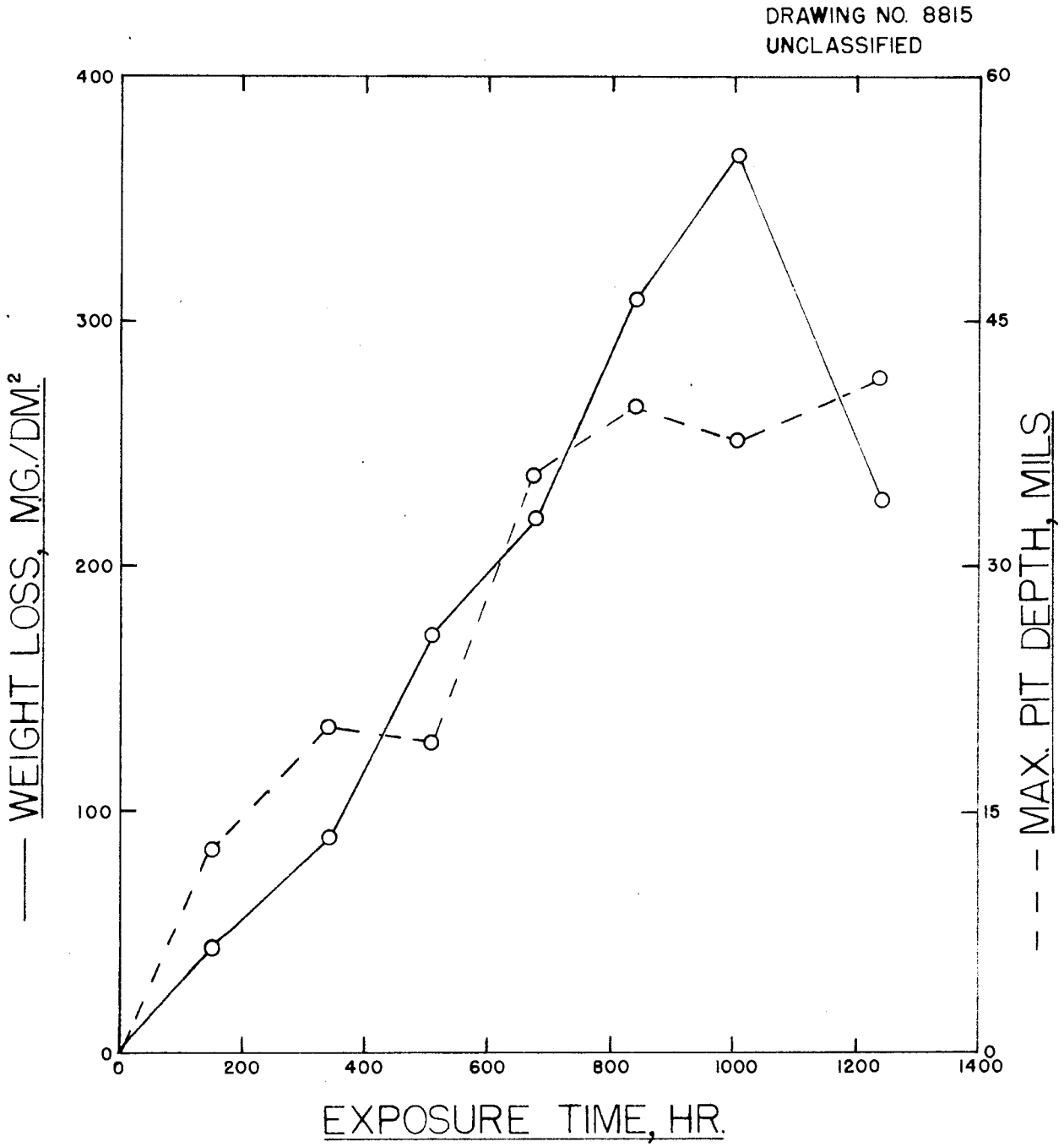


FIG. 17 STAGNANT CORROSION OF 356 ALUMINUM COUPLED TO 347 STAINLESS STEEL IN 0.0005M HYDROGEN PEROXIDE AT 85°C

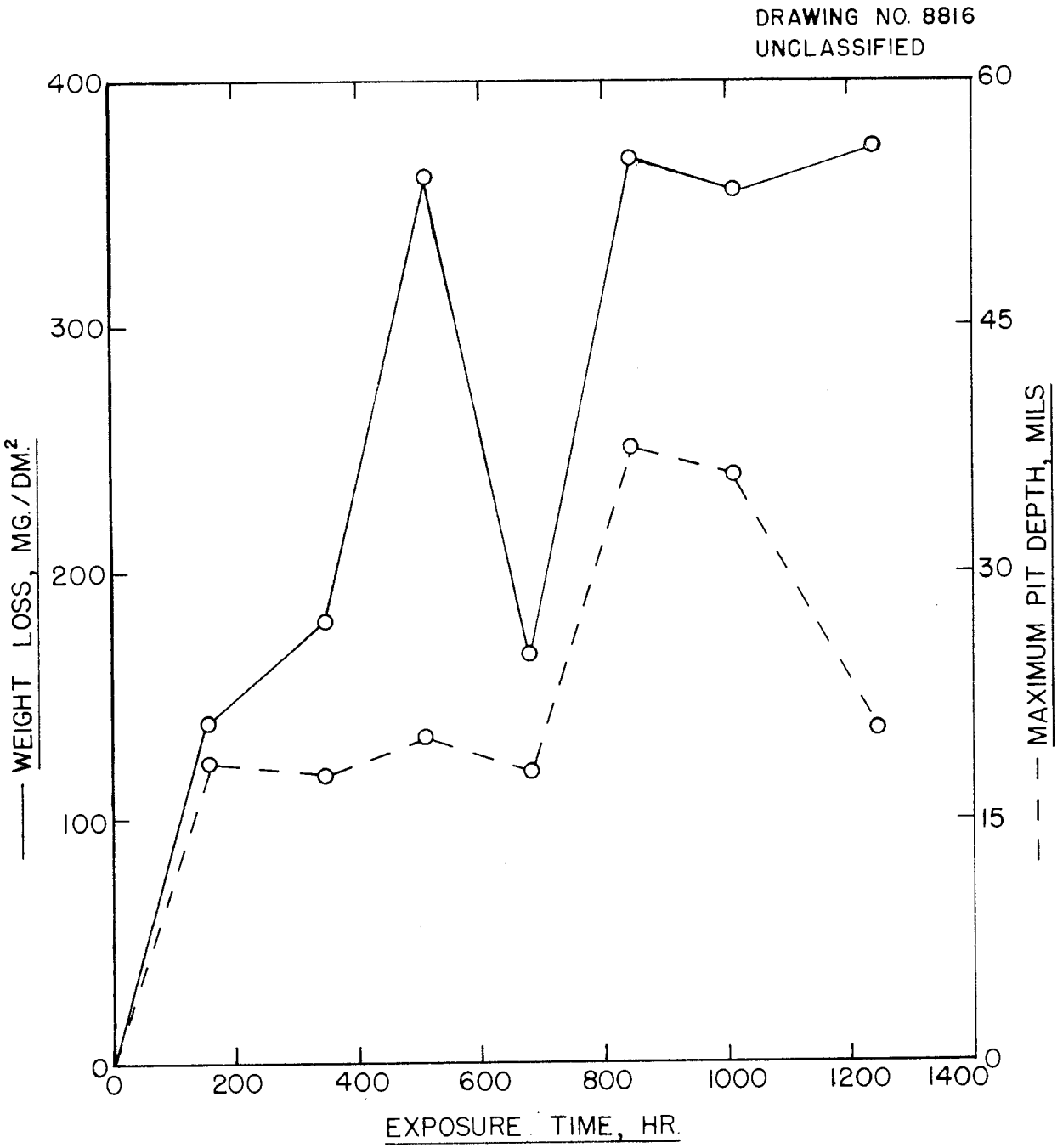


FIG. 18 STAGNANT CORROSION OF 356 ALUMINUM COUPLED TO 347 STAINLESS STEEL IN 0.005M HYDROGEN PEROXIDE AT 85° C

[redacted]

TABLE XXXVI

THE STAGNANT CORROSION OF 356 ALUMINUM-347 STAINLESS STEEL COUPLES IN 0.005M HYDROGEN PEROXIDE CONTAINING 10 PPM. SODIUM CHROMATE AT 85°C

Mat'l	Solution pH	Exposure hr.	Area, cm^2	Pits per cm^2	Max. Pit Depth mils	Max. Pit Dia., mils	Removed Wt. Gain $mg./dm^2$	Defilmed Wt. Loss, $mg./dm^2$	Equivalent Thickness Loss, mil/month
356	6.2	168	16.06	3.7	8.0	80	13.70	9.34	0.059
347	6.2	168	20.42	neg.	neg.	neg.	0.49	0.50	<0.001
356	6.2	336	15.56	3.3	10.8	40	11.56	28.25	0.089
347	6.2	336	20.55	neg.	neg.	neg.	0.48	0.96	0.001
356	6.2	504	15.56	3.9	23.2	100	39.80	1.28	0.003
347	6.2	504	20.55	neg.	neg.	neg.	4.35	0.97	0.001
356	6.2	672	15.36	2.8	6.4	40	16.28	28.65	0.045
347	6.2	672	20.55	neg.	neg.	neg.	7.78	1.46	0.002
356	6.2	840	15.76	3.1	3.6	40	25.36	10.15	0.013
347	6.2	840	20.55	neg.	neg.	neg.	4.87	neg.	neg.
356	6.2	1008	15.76	3.3	9.2	40	81.75	6.34	0.007
347	6.2	1008	20.55	neg.	neg.	neg.	13.63	0.48	<0.001

[redacted]

8.4 347 Stainless Steel (Cont'd)

equation for determining the effectiveness of a chemical as a corrosion inhibitor. This equation is

$$P = \frac{W_1 - W_2}{W_1} (100)$$

where
P = inhibitor effectiveness
W_1 = weight loss of specimen exposed for a definite time to test solution
W_2 = weight loss of similar specimen exposed to a similar solution containing the chemical in question for the same period of time

Substituting data from Tables XXXV and XXXVI for weight losses on 356 aluminum exposed to 0.005M hydrogen peroxide at 85°C, the equation becomes

$$P = \frac{(357.00) - (6.34)}{(357.00)} (100)$$
$$= 95.7$$

According to Mears and Eldredge, a value of 80-100 for P indicates that the chemical under test possesses good corrosion inhibiting qualities.

Figure 19 shows the weight losses and the maximum pit depths reported on the 356 aluminum specimens coupled to 347 stainless steel in 0.005M hydrogen peroxide containing 10 ppm of sodium chromate. These specimens showed gains in weight as removed from the test medium. Corrosion attack on the stainless steel was negligible in all cases.

A complete summary of stagnant corrosion data for 356 aluminum coupled to 347 stainless steel is shown in Figure 20. Test media were deaerated water, 0.0005M and 0.005M hydrogem peroxide, and 0.005M hydrogen peroxide containing 10 ppm of sodium chromate. The best corrosion resistance of 356 aluminum was exhibited in deaerated water. Slightly less corrosion resistant properties were shown in 0.005M peroxide containing 10 ppm of sodium chromate as a corrosion inhibitor. The most severe corrosion attack on the aluminum was encountered in uninhibited 0.005M hydrogen peroxide solution. Corrosion attack in 0.0005M peroxide was almost as severe as in the higher concentration solutions.

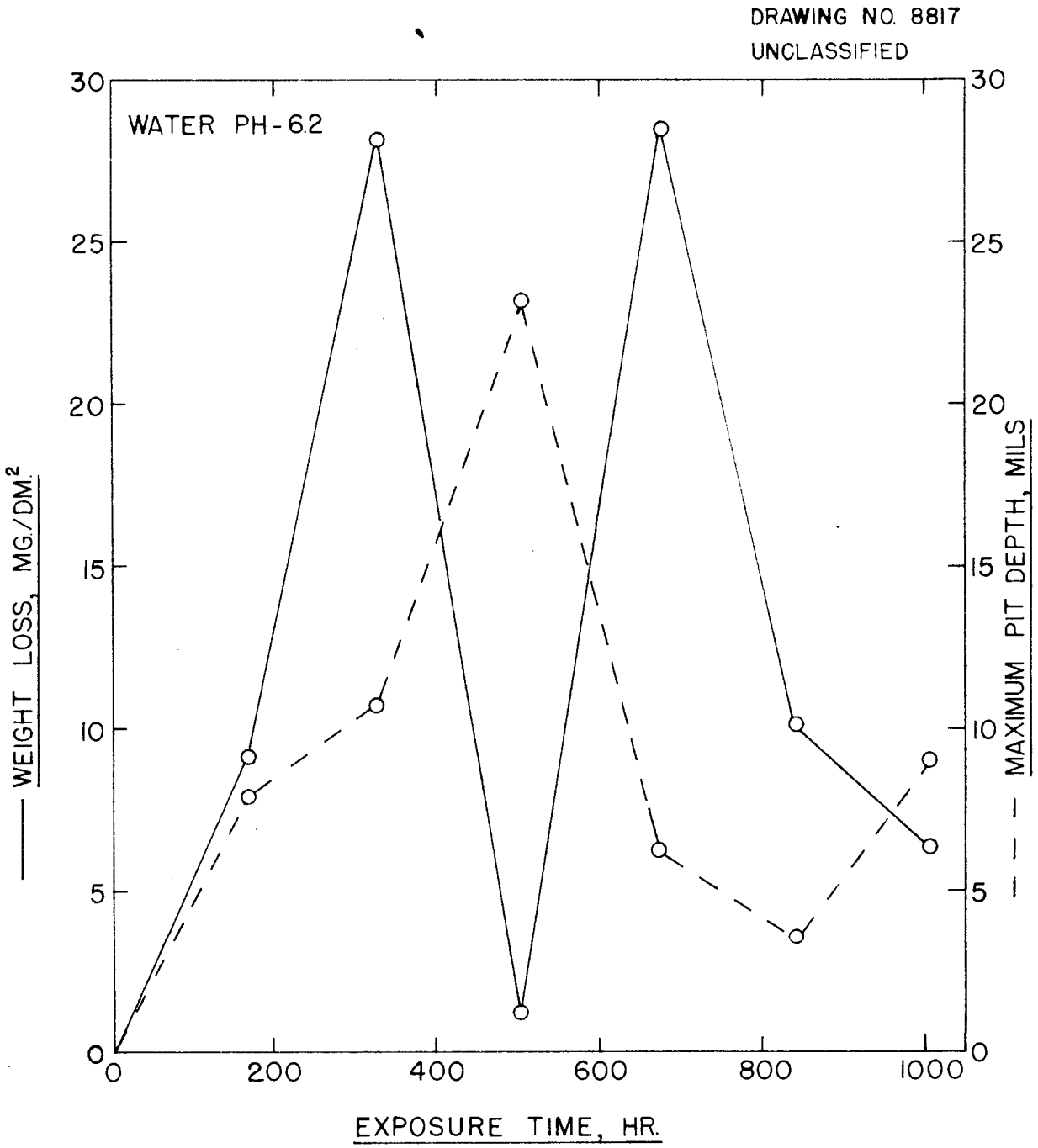
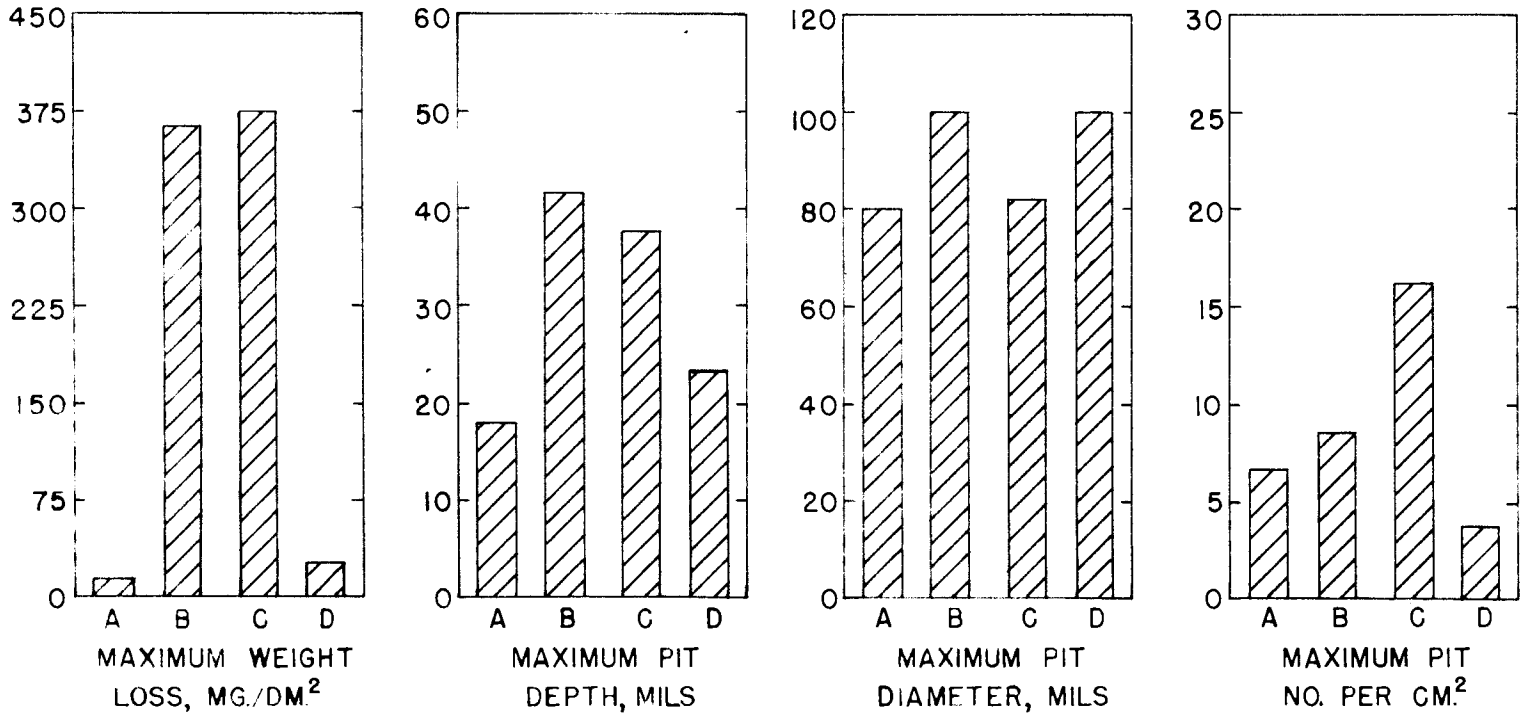


FIG. 19 STAGNANT CORROSION OF 356 ALUMINUM COUPLED TO 347 STAINLESS STEEL IN 0.005M HYDROGEN PEROXIDE CONTAINING 10 PPM. OF SODIUM CHROMATE AT 85°C



KEY A - DEAERATED DEMINERALIZED WATER, PH 6.1-6.2
B - 0.0005 M HYDROGEN PEROXIDE, PH 6.1
C - 0.005M HYDROGEN PEROXIDE, PH 6.1-6.2
D - 0.005M HYDROGEN PEROXIDE + 10 PPM. Na_2CrO_4, PH 6.2

FIG. 20 A COMPARISON OF THE STAGNANT CORROSION ATTACK ON 356 ALUMINUM COUPLED TO 347 STAINLESS STEEL IN VARIOUS MEDIA AT 85°C FOR 1008 HOURS

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8.4 347 Stainless Steel (Cont'd)

In the absence of chemical inhibitors, galvanic corrosion attack on 356 aluminum in contact with 347 stainless steel can be kept to a minimum by deaeration of the cooling water. At the same time, however, it appears that a small concentration of dissolved or free oxygen is necessary in the water to aid in the formation and maintenance of the protective oxide film on the aluminum. If this apparently critical concentration is exceeded, corrosion attack by dissimilar metal contact will increase rapidly. This attack can be greatly lessened, in the presence of high oxygen concentrations by the use of sodium chromate as a corrosion inhibitor. The mechanism of chromate inhibition is believed dependent upon the formation of a chromic oxide film with the normally formed aluminum oxide film resulting in a more non-porous and tightly adherent barrier against corrosive conditions.

9.0 INTERPRETATION OF CORROSION DAMAGE

The methods used for the evaluation of corrosion damage on the test specimens involved visual inspection, loss of weight, and microscopic examination. The former is important in the estimation of corrosion attack because it is simple and differentiates between various types of corrosion attack. It is of value when used in conjunction with other methods of evaluation.

Loss of weight measurements afford a quantitative estimation of corrosion attack. Miscroscopic examination permits quick determinations of surface corrosion effects such as the depth of pits, pit diameters, the number of pits per unit area, and the general condition of the metal surfaces.

The equivalent thickness loss of the specimens was determined by use of the following equation

$$P = \frac{K\,W}{A\,D\,T}$$

where K is a constant, dependent upon the units used to express the penetration rate (i.e., when P is expressed in mils/month, K = 283)

P is the penetration or equivalent thickness loss rate, mils/month

W is the weight loss of the specimen corrected for loss incurred by the defilming method, mg

9.0 INTERPRETATION OF CORROSION DAMAGE (CONT'D)

A is the total exposed surface area, cm^2

T is the exposure time of the specimen, hr

10.0 DISCUSSION OF RESULTS

Photographs of the various types of localized and general corrosion attack on uncoupled and coupled 356 aluminum test specimens are shown in Figure 21-A, B, and C. A brief history of these specimens appears in Table XXXVII.

Corrosion attack on the 356 aluminum was confined completely to surface type of attack. Surface corrosion attack appeared in two forms, pitting attack and general corrosion of the metal surfaces. No evidences of sub-surface corrosion attack were observed during the course of this investigation.

A general disucssion of the corrosion behavior of 356 aluminum exposed to simulated reactor cooling water at 85°C follows. Mention has been made of the nature of the oxide film to which aluminum and its alloys owe their excellent corrosion resistance. The oxygen in the atmosphere or the oxygen present in liquid media such as natural waters is usually sufficient to develop this protective film. However, in the presence of excessive concentrations of oxygen or oxidizing substances, corrosion of the aluminum alloys is stimulated by the diffusion of the oxygen through the protective oxide film on the metal. Such corrosion attack normally appears in the form of a localized attack due to the formation of differential oxygen concentration cells.

Corrosion in Deaerated Water - Stagnant corrosion rates for 356 aluminum in deaerated water at pH of 5.9-6.2 ranged from 0.008-0.062 mil/month. Corrosion attack was more pronounced during the initial period of exposure while the development of the protective oxide film was taking place. The maximum pit depth observed on specimens exposed to deaerated water was 13.7 mils; the average pit depth was 3 mils. Dynamic corrosion rates for 356 aluminum were slightly higher than stagnant rates and ranged from 0.022-0.138 mil/month. This increase in the corrosion rates may be attributed to the wearing effect on the metal surfaces during rotation resulting in longer times required for the formation of the oxide film. The maximum pit depth observed on the dynamic specimens was 8 mils.

Variations in the ionic concentrations of certain constituents in natural and treated waters will greatly determine the corrosion behavior of the aluminum alloy. Oxygen in the water is one of the

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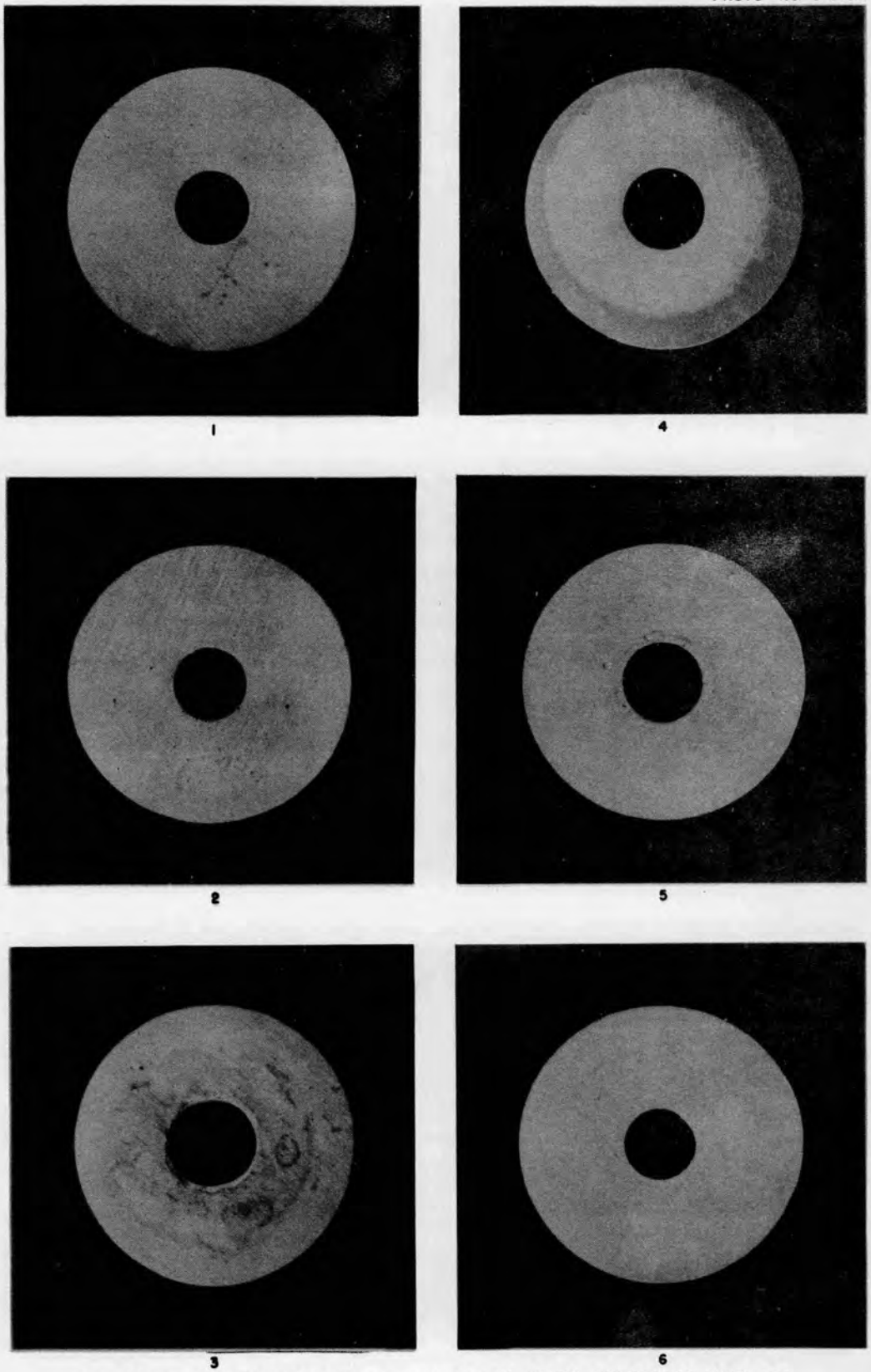

FIG. 21-A PHOTOGRAPH OF 356 ALUMINUM TEST SPECIMENS (MAG. 1.4)

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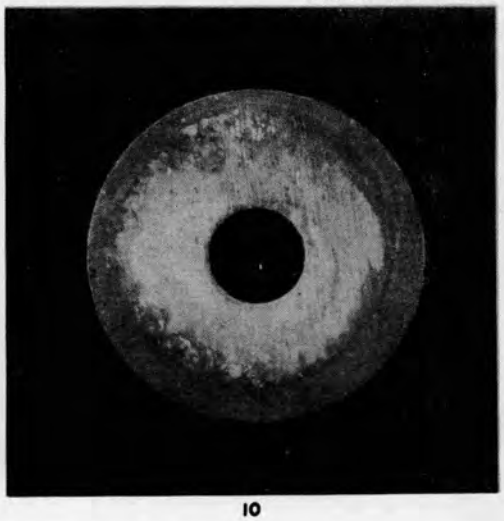

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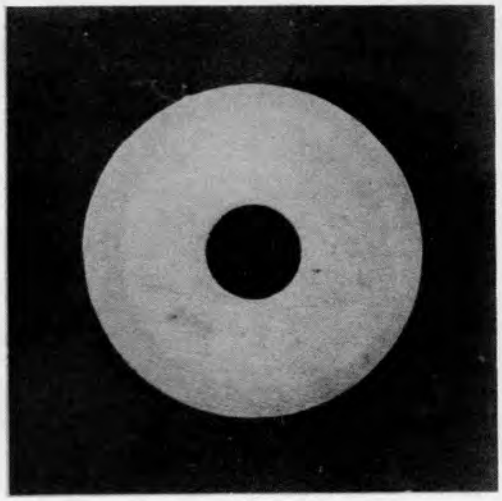

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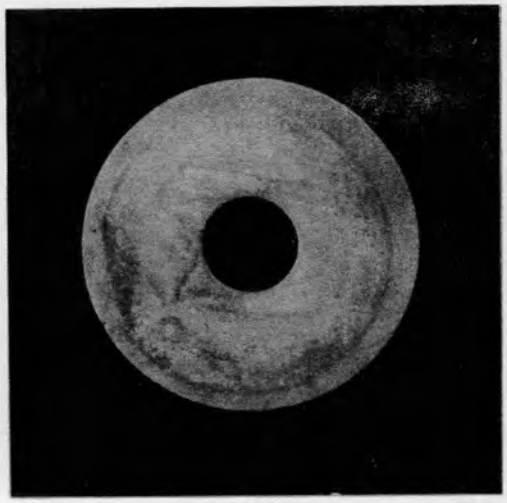

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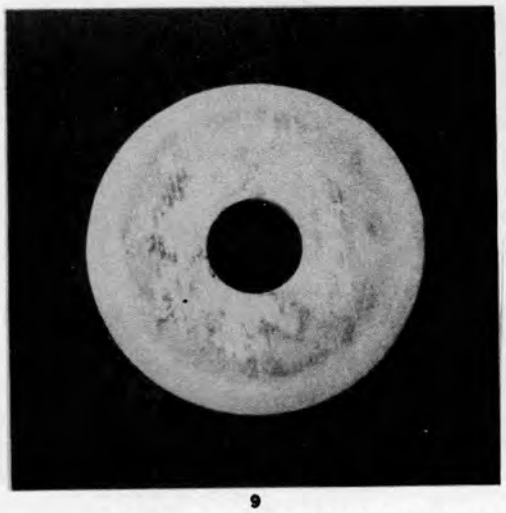

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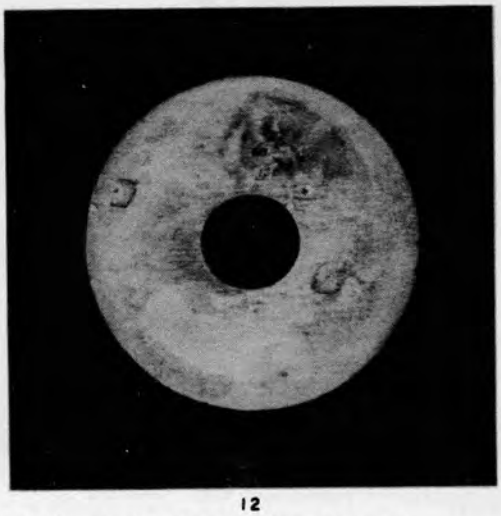

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FIG. 21-B PHOTOGRAPH OF 356 ALUMINUM TEST SPECIMENS (MAG. 1.4)

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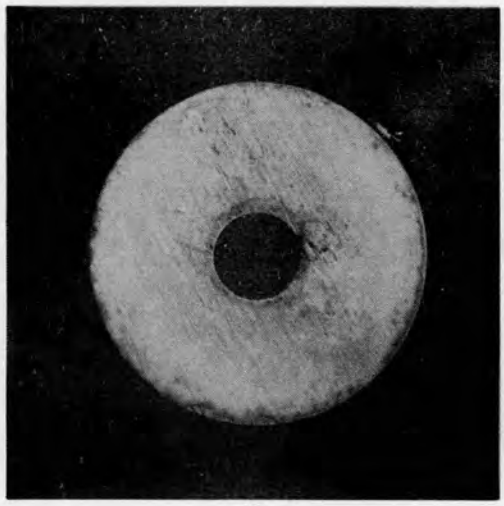

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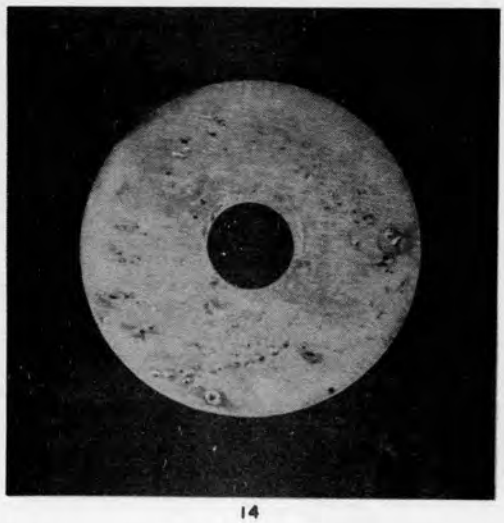

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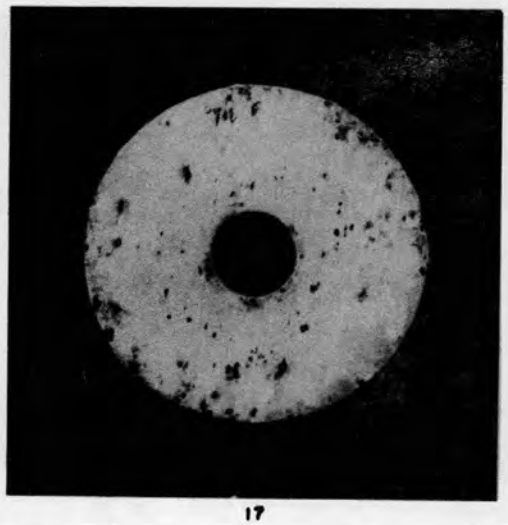

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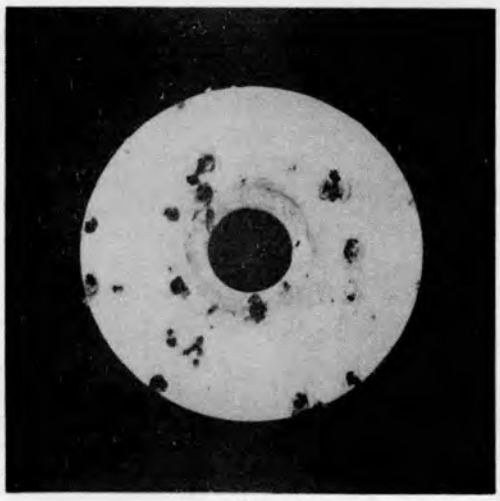

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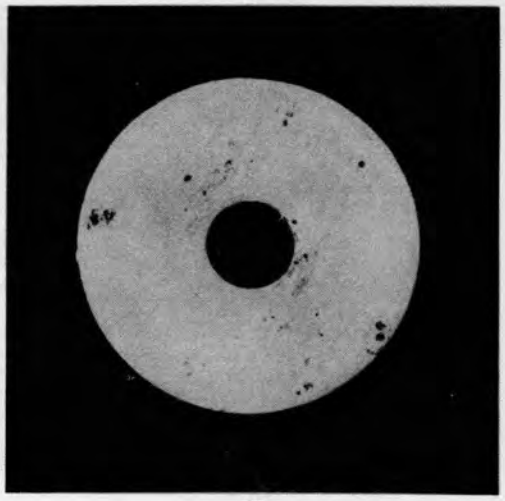

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FIG. 21-C PHOTOGRAPH OF 356 ALUMINUM TEST SPECIMENS (MAG. 1.4)

[redacted]

TABLE XXXVII

DESCRIPTION OF 356 ALUMINUM CORROSION SPECIMENS SHOWN IN FIGURE 21-A, B, AND C

Photograph	Type of Test	Temp °C	pH	Hydrogen Peroxide	Inhibitor, ppm	Exposure Time, hr.	Coupled With
1	Stagnant	85	5.5-6.5	None	None	1008	--
2	Stagnant (aerated)	85	5.5-6.5	None	None	1008	--
3	Stagnant	85	5.5-6.5	0.005M	None	1008	--
4	Stagnant	85	7.5-8.0	0.005M	5 Na_2CrO_4	1008	--
5	Stagnant	85	7.5-8.0	0.005M	5 $Na_2Cr_2O_7$	1008	--
6	Stagnant	85	5.5-6.5	0.005M	None	1008	--
7	Stagnant	85	5.5-6.5	None	None	1008	Beryllium
8	Dynamic	85	5.5-6.5	None	None	1008	Beryllium
9	Stagnant	85	5.5-6.5	0.0005M	None	1008	Beryllium
10	Dynamic	85	5.5-6.5	0.0005M	5 Na_2CrO_4	1008	Beryllium
11	Dynamic	85	7.5-8.0	0.0005M	5 $Na_2Cr_2O_7$	1008	Beryllium
12	Stagnant	85	5.5-6.5	0.005M	None	1008	Beryllium
13	Stagnant	85	5.5-6.5	0.0005M	None	1008	2S Aluminum
14	Stagnant	85	5.5-6.5	None	None	1008	347 S.S.
15	Stagnant	85	5.5-6.5	0.0005M	None	1008	347 S.S.
16	Stagnant	85	5.5-6.5	0.005M	None	1008	347 S.S.
17	Stagnant	85	5.5-6.5	0.005M	None	1008	347 S.S.
18	Stagnant	85	5.5-6.5	0.005M	10 Na_2CrO_4	1008	347 S.S.

[redacted]

10.0 DISCUSSION OF RESULTS (CONT'D)

most variable corrosive agents. Soft waters and waters containing high concentrations of carbon dioxide will be slightly more corrosive. High chloride and sulfate contents will also increase the corrosive nature of water.

High concentrations of iron and copper ions will interfere with the formation of a protective film on aluminum. These ions are relatively strong oxidizing agents and may exist as soluble salts in an oxidized or reduced state depending on their contact with air or oxygen in the water. These salts tend to produce soluble metal salts rather than oxides and do not form protective films as readily as some other oxidizing agents. Copper may precipitate by contact on the aluminum resulting in a form of galvanic corrosion.

Corrosion in Aerated Water - The stagnant corrosion rate of 356 aluminum was increased in aerated, demineralized water at 85°C. In a test to determine the effect of aeration on the corrosion of the alloy, a corrosion rate of 0.18 mil/month was obtained as compared to 0.006 mil/month in deaerated water. Pitting attack was more pronounced on the specimen exposed to aerated water. The corrosion of aluminum in water containing oxygen is a more spontaneous reaction than the corrosion of aluminum in oxygen-free water. This effect is discussed in Section 7.2 of this report.

The Effect of Temperature on Corrosion - In 0.005M hydrogen peroxide solutions, the maximum corrosion attack on 356 aluminum occurred at a temperature of 50°C. The magnitude of this attack was 0.036 mil/month. Corrosion attack at 30°C was 0.007 mil/month; at 90°C, the magnitude of attack was 0.011 mil/month. Localized attack was more pronounced on the specimen exposed at 50°C. The maximum pit depth reported on this specimen was 8.5 mils. The frequency of pit distribution decreased nearly linearly from 5.2 to 0.2 pits per sq cm as the temperature increased from 30°C to 90°C.

Corrosion in 0.0005M Hydrogen Peroxide - The dynamic corrosion rate of 356 aluminum in 0.0005M hydrogen peroxide solutions was greater than stagnant rates. Values of 0.007-0.137 mil/month was reported for the former as compared to 0.002-0.031 mil/month for the stagnant specimens. Maximum pit depths of 2.8 and 9.6 mils were observed on the dynamic and stagnant test specimens, respectively. The frequency of pits on the dynamic specimens was greater by a factor of 4 as compared to the stagnant specimens.

10.0 DISCUSSION OF RESULTS (CONT'D)

Corrosion in 0.005M Hydrogen Peroxide - Stagnant corrosion rates for stagnant 356 aluminum specimens in 0.005M hydrogen peroxide ranged from 0.006-0.068 mil/month; dynamic corrosion rates were 0.003-0.049 mil/month. In general, the corrosion resistance of the aluminum was better in the 0.005M peroxide solutions than in 0.0005M hydrogen peroxide. The maximum pit depth observed on the stagnant specimens was 12 mils; on dynamic specimens, the maximum pit depth was 4 mils. The greatest frequency of pits was found also on the stagnant specimens. This value was 7.3 pits per sq cm.

The Effect of Corrosion Inhibitors - The addition of 10 ppm of sodium chromate to deaerated water at pH of 6.0-6.2 was very effective for reducing localized attack. The corrosion rates under stagnant conditions were nearly identical with uninhibited corrosion rates which were almost negligible for exposures of 1008 hours. Pitting attack was negligible also on these specimens.

In 0.0005M hydrogen peroxide solutions, the effect of 10 ppm of sodium chromate was beneficial for reducing the magnitude of corrosion attack on 356 aluminum. Pitting attack was almost eliminated completely. The corrosion rate of stagnant specimens for 1008 hours exposure was 0.013 mil/month. These tests were conducted with a water pH of 6.0-6.2. When the pH of the 0.0005M peroxide solution was increased to 7.5-7.8, the corrosion attack on the aluminum in the presence of 10 ppm of sodium chromate increased drastically. The maximum metal thickness loss was 0.512 mil/month, and the surfaces of the specimens were heavily etched.

A slight reduction in the corrosion rate for 356 aluminum in 0.005M hydrogen peroxide solutions at pH of 6.1 containing 10 ppm of sodium chromate was observed. There was little indication of any beneficial influence, however, on a reduction of localized attack. A metal thickness loss of 0.026 mil/month was reported for an exposure of 1008 hours.

Sodium dichromate in concentrations of 5 ppm was added to 0.0005M and 0.005M hydrogen peroxide solutions at a pH of 7.8. Pitting attack on the specimens was negligible but the corrosion rates were abnormally high in magnitude. These rates were 0.119-0.310 mil/month in 0.0005M peroxide, and 0.156-0.387 mil/month in 0.005M hydrogen peroxide solutions.

The Effect of Heat Treatment - A comparison between the corrosion resistance of cast 356 aluminum and heat treated 356 aluminum, designated as 356T-7, indicated that the cast material showed a slightly superior corrosion resistance to stagnant 0.0005M and 0.005M hydrogen

10.0 DISCUSSION OF RESULTS (CONT'D)

peroxide solutions. The average corrosion rate for the cast material in the peroxide solutions was 0.007 mil/month. Localized attack on both types of alloy was nearly the same in intensity and frequency.

Galvanic Corrosion Behavior with 2S Aluminum - Contact couples of 356 aluminum and 2S aluminum were tested in deaerated water, 0.0005M hydrogen peroxide, and 0.005M hydrogen peroxide solutions. In all tests, 356 aluminum was preferentially attacked. The intensity of this attack varied directly with the concentration of hydrogen peroxide present in the test medium. Pitting attack on the 356 aluminum was predominantly located on the surface in immediate contact with the 2S aluminum. For exposures of 1008 hours, the corrosion rates for coupled 356 aluminum in deaerated water, 0.0005M hydrogen peroxide, and 0.005M hydrogen peroxide were 0.009, 0.008, and 0.024 mil/month, respectively.

Sodium chromate in concentrations of 10 ppm in 0.0005M hydrogen peroxide solutions showed little or no beneficial influence on the corrosion resistance of 356 aluminum coupled to 2S aluminum. A corrosion rate of 0.007 mil/month was obtained for an exposure of 1008 hours. Localized corrosion attack was not materially reduced by the sodium chromate.

Galvanic Corrosion Behavior with 43 Aluminum - Cast and heat treated 356 aluminum specimens were coupled to 43 aluminum casting alloy and exposed to stagnant 0.0005M and 0.005M hydrogen peroxide solutions. A slight preferential corrosion attack occurred on the 356 aluminum specimens. The maximum corrosion rate reported was on a 356T-7 specimen coupled to 43 aluminum in 0.005M hydrogen peroxide. This rate was 0.023 mil/month. The corrosion resistance of the coupled cast 356 aluminum was slightly better than that of the heat treated 356 aluminum.

Galvanic Corrosion Behavior with Extruded Beryllium - The corrosion rates of 356 aluminum coupled to extruded beryllium were nearly the same for stagnant and dynamic conditions in deaerated water. These rates averaged 0.052 mil/month for exposures of 1008 hours. The aluminum was preferentially attacked in both cases. In stagnant and dynamic tests in 0.0005M and 0.005M hydrogen peroxide solutions, the beryllium metal was preferentially attacked rather than the 356 aluminum. For exposures of 1008 hours, the corrosion rate of 356T-7 aluminum was 0.019 mil/month under stagnant conditions; for the same exposure period, the stagnant corrosion rate for cast 356 aluminum was negligible. The dynamic corrosion rate for 356T-7 aluminum was 0.014 mil/month. Although the beryllium was preferentially attacked, the deepest pits appeared on the aluminum specimens. A maximum depth of 24.8 mils was observed. The greatest distribution of pits appeared on the beryllium specimens, however, and averaged 5.2 pits per sq cm.

10.0 DISCUSSION OF RESULTS (CONT'D)

Concentrations of 5 ppm of sodium chromate in 0.0005M hydrogen peroxide had little effect in reducing the frequency and intensity of localized attack on the 356 aluminum specimens. In these tests, 356 aluminum suffered preferential corrosion attack. The pH of the test solutions greatly influenced the corrosion rate of the aluminum alloy. At pH of 6.1, the stagnant and dynamic corrosion rates were 0.001 and 0.037 mil/month. With the pH increased to 7.7, these rates increased to 0.199 and 0.460 mil/month, respectively.

Galvanic Corrosion Behavior with 347 Stainless Steel - In stagnant, deaerated water, 356 aluminum coupled to 347 stainless steel exhibited a slight preferential attack. The corrosion rate of 356 aluminum for 1008 hours exposure was 0.012 mil/month. Pitting attack on the area in immediate contact with the stainless steel was rather prolific and pit counts of 2.4-6.7 pits/sq cm were reported. Corrosion attack on the 356 aluminum increased rapidly in hydrogen peroxide solutions. After an exposure of 1240 hours, the corrosion rate of the aluminum in 0.0005M hydrogen peroxide was 0.156 mil/month; in 0.005M peroxide, this rate increased to 0.321 mil/month. Pitting attack was extremely severe in both solutions and pits ranging in depth from 12.8 to 41.6 mils were reported.

The addition of 10 ppm. of sodium chromate to 0.005M hydrogen peroxide solutions had a marked effect on the corrosion resistance of the coupled 356 aluminum. Corrosion rates were lowered to 0.008 mil/month under stagnant conditions in exposures of 1008 hours. The intensity of pitting attack was also decreased noticeably. On a specimen exposed for 1008 hours, the maximum pit depth observed was 9.2 mils. In all tests, corrosion attack on the stainless steel was negligible.

General Remarks - The rate of corrosion of aluminum is controlled by the formation of a protective oxide film which forms when aluminum surfaces are exposed to the atmosphere. This film is very thin (ca 0.000001 cm.) and tightly adherent. In neutral or nearly neutral waters, the corrosion mechansim of aluminum is accompanied by the formation of an auxiliary hydrated aluminum oxide film. This film acts as an additional barrier layer against further corrosion attack. In some solutions, corrosion attack may be rapid initially, but as the insoluble products of the reaction are formed, an adherent, continuous film grows over the metal surfaces, preventing contact of the corrosion medium with the underlying metal. As a result of this film formation, corrosion attack is greatly reduced or stopped. During the present corrosion studies with 356 aluminum, it was observed in many cases that an incubation period of 500-700 hours was required for the development of the hydrated oxide film before corrosion attack was retarded. In other instances, with slightly different compositions of

10.0 DISCUSSION OF RESULTS (CONT'D)

test media, it was observed that there was no apparent protection afforded the aluminum specimens against corrosion attack. This effect may be attributed to the fact that dissolution of the oxide film occurred or that breakdown took place in the film thus permitting the corrosive media to come into immediate contact with the base metal and allowing corrosion attack to progress unhindered. Based on these observations, it would appear that a preliminary treatment of the aluminum alloy to augment the oxide film already present on the metal would be beneficial. Such a treatment might consist of immersing the alloy in boiling water of a high quality.

An important observation made during the course of the corrosion study was the fact that a major proportion of the 356 aluminum test specimens showed a weight gain after they were removed from the various test media and before any defilming operation was undertaken. Exceptions to this behavior occurred on 356 aluminum specimens coupled to 357 stainless steel in 0.0005M and 0.005M hydrogen peroxide solutions. In these cases, actual weight losses were reported on the specimens upon their removal from the test media. The weight gains exhibited by the specimens were due to the formation of a hydrated oxide film and insoluble corrosion products on the metal surfaces during exposure. Corrosion attack on these samples showing weight gains was limited to a localized or pitting type of attack. The equivalent thickness loss rates expressed in this report are based on a defilmed weight loss. The defilming process is used to remove the oxide and insoluble corrosion product films formed on the specimens. These defilmed weight losses are corrected for weight loss of the base metal due to attack by the defilming medium.

The presence of free or dissolved oxygen in water is an important factor in determing the corrosion behavior of 356 aluminum. Small concentrations of oxygen are necessary for the formation and maintenance of the protective oxide film. In corrosion tests with deaerated water which contained a few ppm of oxygen, the corrosion resistance of uncoupled and coupled 356 aluminum was usually superior to the resistance obtained in 0.0005M and 0.005M hydrogen peroxide solutions. In oxygen-free waters, the corrosion of aluminum proceeds with the formation of a film of electrically neutral hydrogen atoms on the metal surfaces. The presence of this film serves as an insulating blanket against the progress of the normal corrosion reaction. The hydrogen atoms polarize the metal surfaces and the rate of corrosion will depend greatly upon the rate at which the hydrogen film is removed. Since oxygen is a strong depolarizing agent, it combines readily with the atomic hydrogen and removes it from the surfaces. Thus, the protective influence of the hydrogen blanket is removed. In waters containing hydrogen peroxide, the presence of oxygen is assured through decomposition of the peroxide by various factors including temperature,

10.0 DISCUSSION OF RESULTS (CONT'D)

solution pH, presence of heavy metal ions such as copper and iron, and others. With increased concentrations of oxygen, the more rapid will be the rate of depolarization, and the more intense will be the extent of corrosion attack. These facts were verified by tests included in this report.

Galvanic corrosion attack is a result of a current flow between dissimilar metals in electrical contact with each other in an electrolyte. The conductivity of the electrolyte will greatly determine the extent of this type of attack. Corrosion attack occurs on the anodic or less noble member of the couple and is generally localized. Near the junction of two coplanar metal surfaces, the intensity of attack on the anodic metal increases as the boundary is approached. The corrosion attack is greater in strongly conducting solutions than in poorly conducting solutions, but the attack will be widely distributed in the first instance and only localized along the boundary in the second case. This phenomenom makes the use of dissimilar metals in contact less dangerous for certain application than would appear at first sight.

The ratio of anodic area to cathodic area is an important factor in determining the extent and intensity of corrosion attack suffered by the less noble member of the couple. A small anode to cathode area ratio results in severe intensification of corrosion attack on the anode. The anode to cathode area ratios for test specimens used in this investigation were 1:1.5. Corrosion attack on the anode member of this area ratio couple would be more intense than on the anode member of a couple in which the ratio of anode to cathode area was, say, 10:1.

A complete summation of the results of the corrosion investigation with 356 aluminum is shown graphically in Figure 22, 23, 24, 25, and 26.

In conclusion, the corrosion resistance of 356 aluminum in simulated cooling water for the Materials Testing Reactor appears acceptable and its use should not present any particular corrosion hazard. The control of cooling water quality will improve the corrosion resistance of the aluminum. On the results of this study, a water pH of 5.5-6.5 seems most desirable for best corrosion resistance; the oxygen content of the water should be maintained at low level by regular and frequent degassification operations; the water should be kept free of insoluble foreign particles, and finally, the content of such deleterious ions as chlorides, sulfates, iron, and copper should be maintained at a low level of concentration by suitable chemical treatment of the water. Points of dissimilar contact where the area

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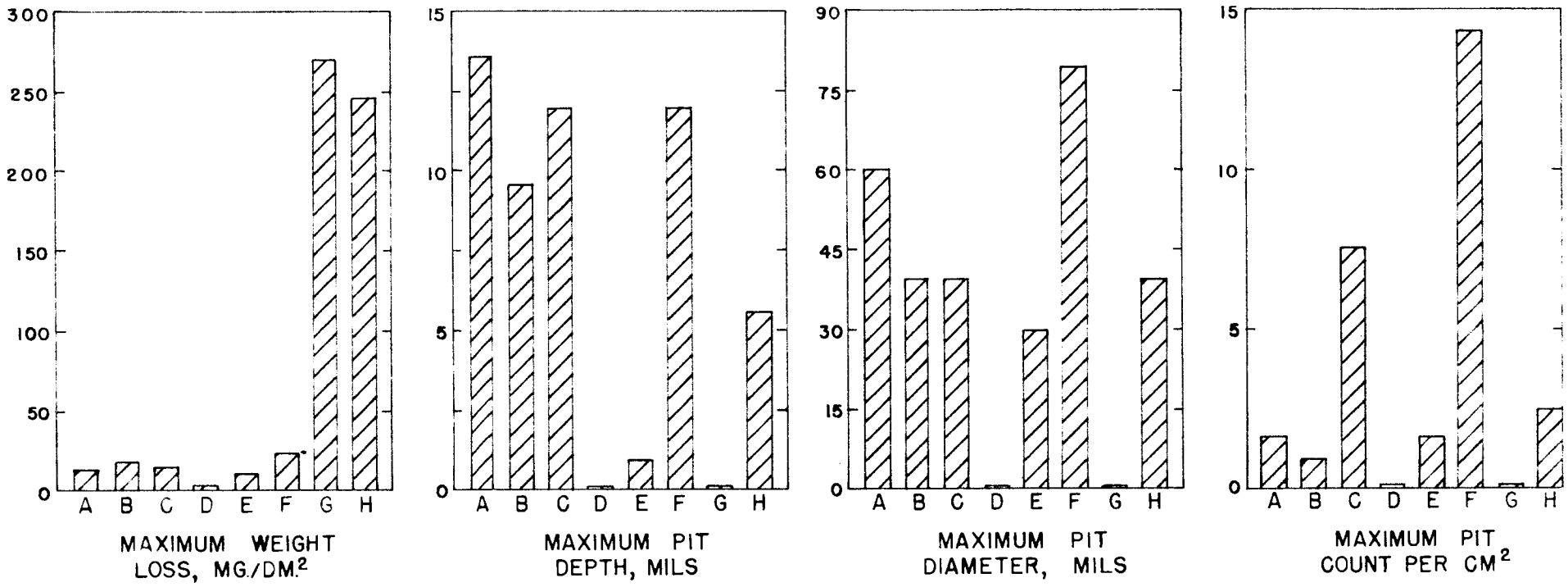

KEY
A - DEAERATED DEMINERALIZED WATER, PH 5.9-6.2
B - 0.0005 M HYDROGEN PEROXIDE, PH 6.0-6.3
C - 0.005 M HYDROGEN PEROXIDE, PH 6.1-6.3
D - DEAERATED WATER + 10 PPM. SODIUM CHROMATE, PH 6.0-6.2
E - 0.0005 M HYDROGEN PEROXIDE + 10 PPM. SODIUM CHROMATE, PH 6.1-6.2
F - 0.005 M HYDROGEN PEROXIDE + 10 PPM. SODIUM CHROMATE, PH 6.1-6.2
G - 0.005 M HYDROGEN PEROXIDE + 5 PPM. SODIUM DICHROMATE, PH 7.8
H - 0.0005 M HYDROGEN PEROXIDE + 5 PPM. SODIUM DICHROMATE, PH 7.7-7.8

FIG. 22 A SUMMARY OF THE STAGNANT CORROSION OF UNCOUPLED 356 ALUMINUM IN VARIOUS TEST MEDIA AT 85°C FOR 1008 HOURS

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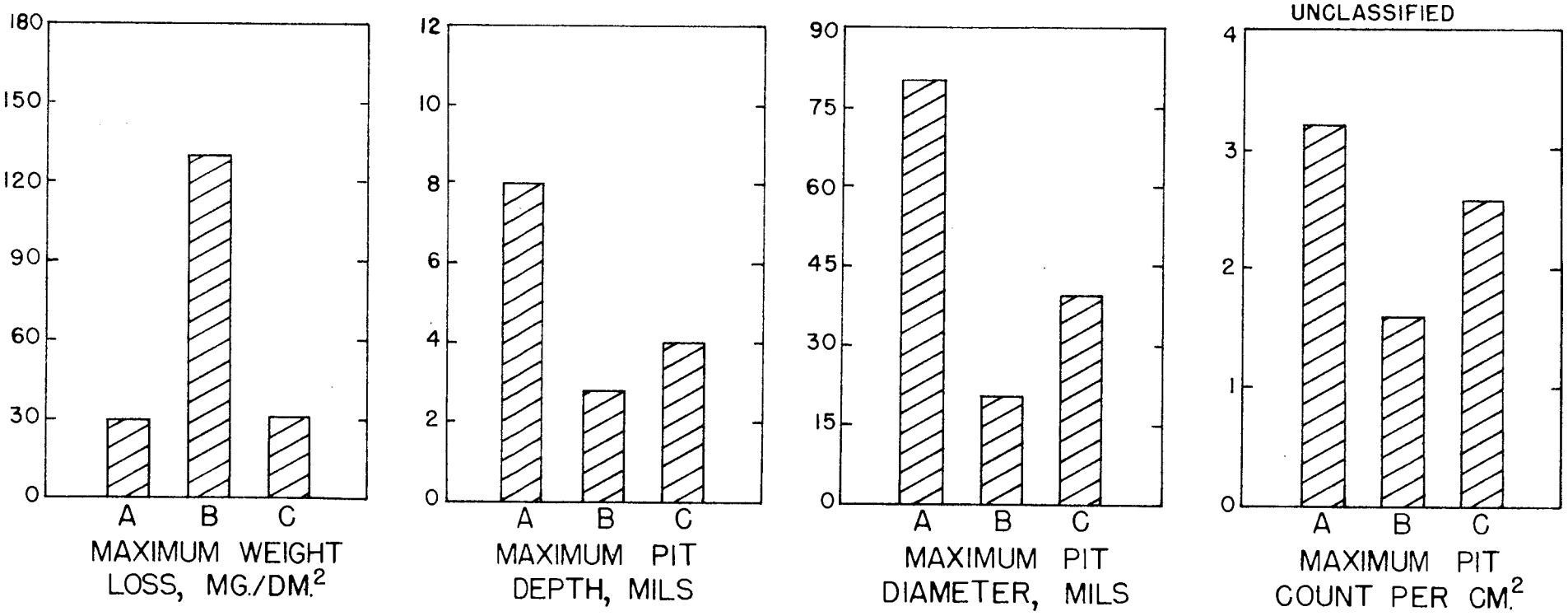
UNCLASSIFIED



KEY A – DEAERATED DEMINERALIZED WATER, PH 6.2
B – 0.0005 M HYDROGEN PEROXIDE, PH 6.0 - 6.2
C – 0.005 M HYDROGEN PEROXIDE, PH 6.1

FIG. 23 A SUMMARY OF THE DYNAMIC CORROSION OF UNCOUPLED 356 ALUMINUM IN VARIOUS TEST MEDIA AT 85°C FOR 1008 HOURS (SPECIMEN VELOCITIES, 6-8 FT./SEC.)

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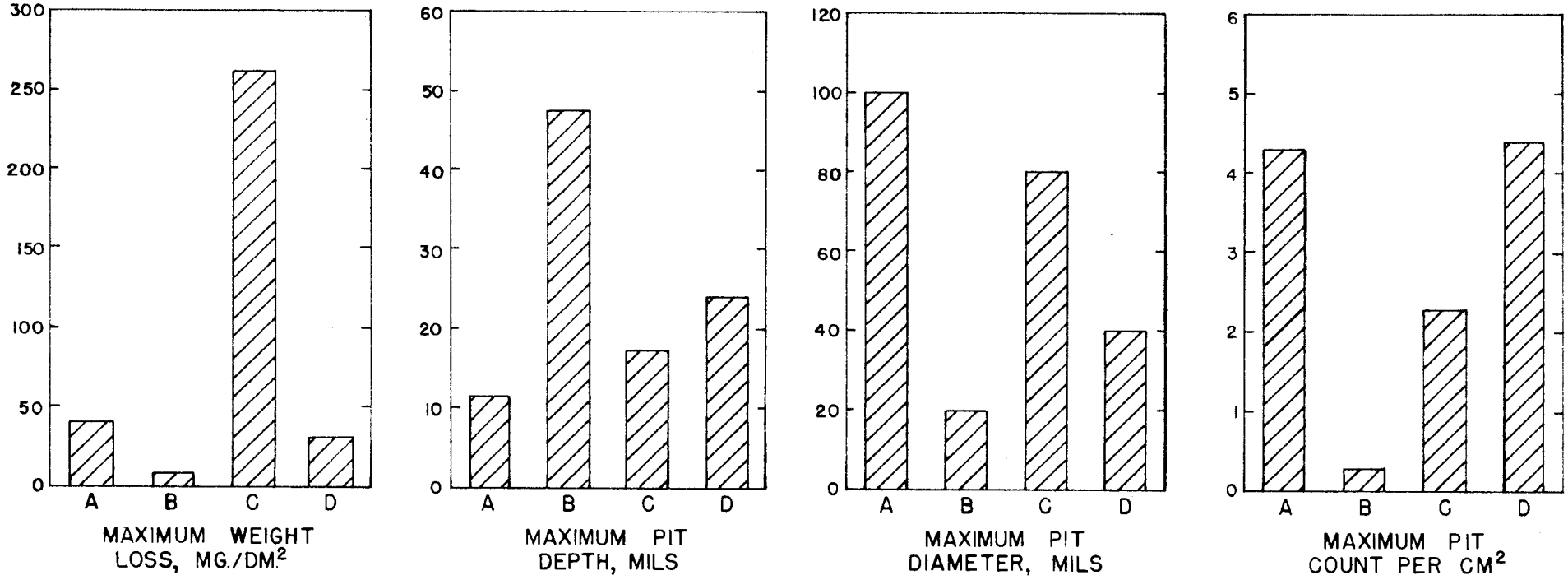
UNCLASSIFIED



KEY
A - DEAERATED DEMINERALIZED WATER, PH 6.1
B - 0.0005M HYDROGEN PEROXIDE, PH 6.1
C - 0.005M HYDROGEN PEROXIDE, PH 6.1
D - 0.0005M HYDROGEN PEROXIDE + 10 PPM. SODIUM CHROMATE, PH 6.1

FIG. 24 A SUMMARY OF THE STAGNANT CORROSION OF 356 ALUMINUM COUPLED TO 2S ALUMINUM IN VARIOUS TEST MEDIA AT 85°C FOR 1008 HOURS

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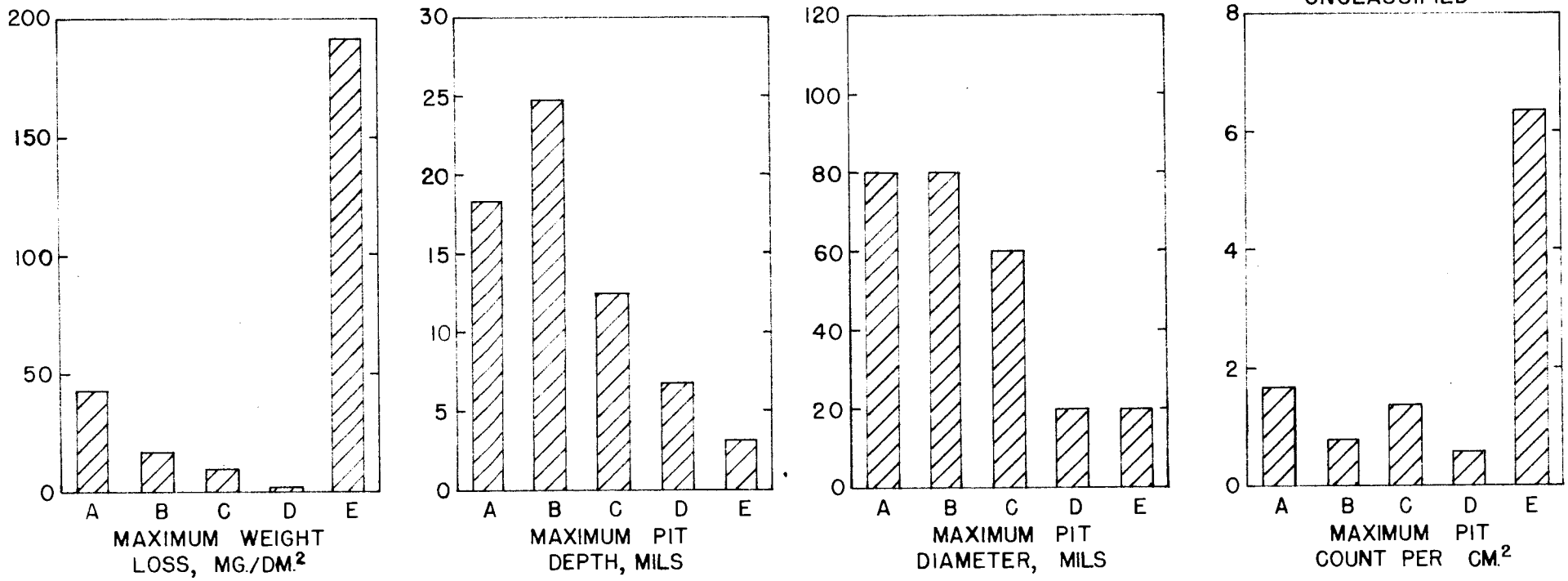
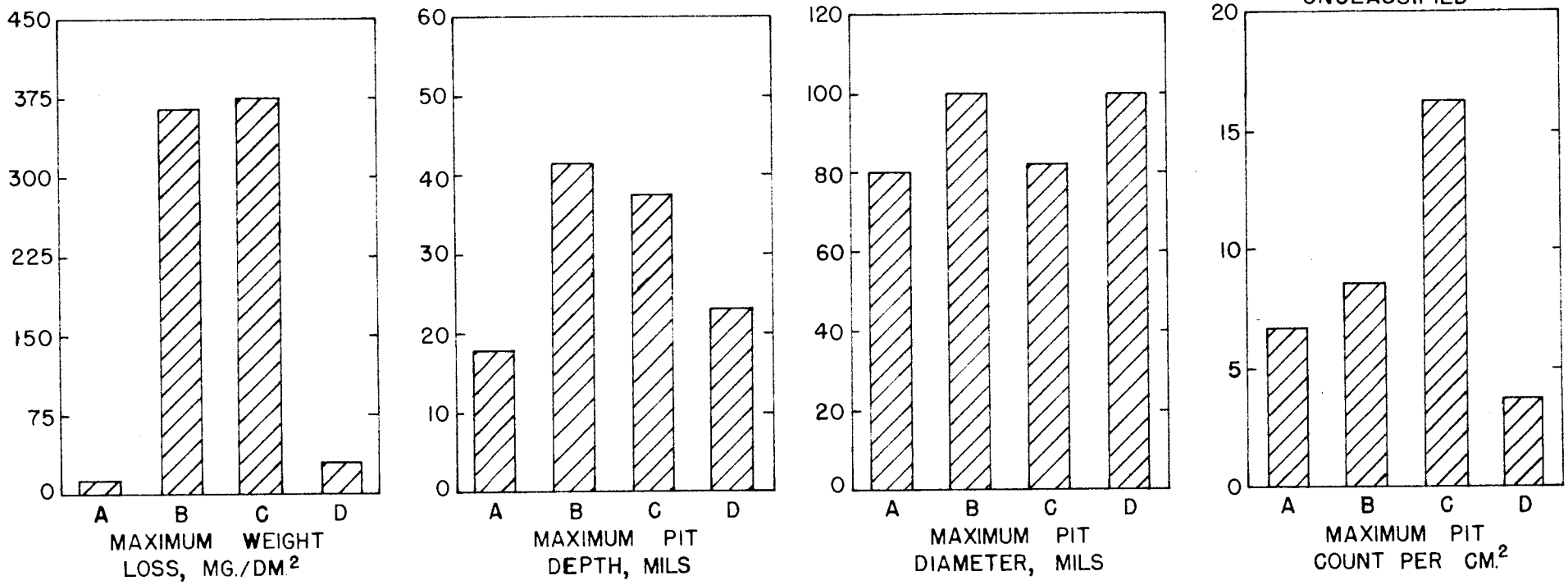
UNCLASSIFIED



KEY
A - DEAERATED DEMINERALIZED WATER, PH 6.1
B - 0.0005 M HYDROGEN PEROXIDE, PH 6.1
C - 0.005 M HYDROGEN PEROXIDE, PH 6.2
D - 0.0005 M HYDROGEN PEROXIDE + 5 PPM. SODIUM CHROMATE, PH 6.1
E - 0.0005 M HYDROGEN PEROXIDE + 5 PPM. SODIUM CHROMATE, PH 7.7

FIG. 25 A SUMMARY OF THE STAGNANT CORROSION OF 356 ALUMINUM COUPLED TO EXTRUDED BERYLLIUM IN VARIOUS TEST MEDIA AT 85°C FOR 1008 HOURS

DRAWING NO. 8822
UNCLASSIFIED



KEY
A - DEAERATED DEMINERALIZED WATER, PH 6.1-6.2
B - 0.0005 M HYDROGEN PEROXIDE, PH 6.1
C - 0.005 M HYDROGEN PEROXIDE, PH 6.1-6.2
D - 0.005 M HYDROGEN PEROXIDE + 10 PPM. SODIUM CHROMATE, PH 6.0

FIG. 26 A SUMMARY OF THE STAGNANT CORROSION OF 356 ALUMINUM COUPLED TO 347 STAINLESS STEEL IN VARIOUS TEST MEDIA AT 85°C FOR 1008 HOURS

10.0 DISCUSSION OF RESULTS (CONT'D)

of 356 aluminum is small compared to the area of the more noble contact metal may present slight pitting problems. Sodium chromate in concentrations of 10 ppm is beneficial for reducing localized attack caused by galvanic couple action.

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J. L. English

J. L. English