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For The Atomic Energy Commission

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THE CORROSION OF ALUMINUM IN DILUTE SOLUTIONS:
LABORATORY STUDIES

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SUMMARY

Problem Under Investigation

After it had been decided that aluminum was to be used as a corrosion-resistant material with good heat transfer properties, it was desired to determine the operating conditions to be used in the water-cooled H.E.W. plant in order to avoid danger of corrosion penetration of thin aluminum parts.

The studies here reported were undertaken with the object of determining these conditions by investigating the effects of all the known variables which might influence the corrosion behavior of aluminum in a water-cooled plant at H.E.W.

The addition of hydrogen peroxide to the testing solutions was the only effort made to simulate special conditions in the plant.

Important Results

An extensive laboratory investigation has been made to determine the corrosion behavior of 2S aluminum under conditions designed to simulate those at the H.E.W. Plant.

The effects of several variables, which were of interest to H.E.W. operation have been investigated and a theory to explain the phenomena observed has been proposed, which involves the formation of a mechanically stronger oxide film at 95°C than at 70°C. No direct evidence is given to support this theory.

pH (measured at 30°C):- 2S aluminum corrosion rates were minimum within the general pH range from 5.5 to about 7.0, with the least danger due to corrosion at pH near 6.5, in the absence of corrosion inhibitors. Lowering the pH caused increased pitting. When 2 ppm $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ was present at pH between 7 and 8, only very mild attack occurred, with danger of penetration of aluminum parts very slight, at temperatures from 70 to 95°C. In the absence of dichromate, areas of local attack were found in this pH range, believed due to local turbulence and other external factors.

The major part of the work reported was done at pH near 6.5, in solutions containing dilute H_2O_2 , chloride, usually calcium and magnesium sulfates, all at the concentrations expected at H.E.W.

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Results on 2S at pH near 6.5: Temperature flow rate, chloride, hydrogen peroxide, Calgon, calcium and magnesium sulfates, preformed oxide films, sodium nitrate and nitrite, Waste Sulfite Liquor, Surface Preparation:- At the lower flow rates (9 ft/sec) increasing the temperature caused more rapid corrosion, while at higher flow rates (20-25 ft/sec) no effect of temperature on corrosion rate was observed.

At 70°, and less so at 80°C, increasing the flow rate from 9 to 25 ft/sec caused increases in the corrosion noted. At 95°C, no such effect was believed to have been shown (evidence scanty).

Chloride ion in solution above 2 ppm increased the amount of corrosion observed to occur in these solutions at 9 ft/sec flow rate. The effect was much more noticeable at 95°C than at 70°C.

Hydrogen peroxide caused only very minor changes in the corrosion observed from zero to 10^{-3} normal, in no case causing severe increase in corrosion rate or local attack.

Calgon caused general increase in corrosion by its presence in solution from 3 to 11 ppm.

No consistent influence on corrosion due to the addition of calcium and magnesium sulfates (20 ppm Ca^{++} , 6 ppm Mg^{++}) to distilled water could be found.

Pre-formed oxide films offered temporary protection from corrosion (up to about 250 hours at 15 ft/sec flow rate, 80°C). Anodization and fuming nitric acid were used.

Sodium nitrate, a possible oxidizing inhibitor, showed only slight corrosion inhibition. Sodium nitrite similarly offered only very slight protection at concentrations up to 14 ppm.

Kimberly-Clark waste Sulfite Liquor, present at 5 ppm, caused a considerable increase in corrosion over that observed in its absence, tested at 25 ft/sec flow rate.

Texas soluble oil C showed no noticeable influence on 2S aluminum corrosion, when present up to 7%.

Different types of sample surface preparation resulted in somewhat different rates of attack in non-flowing systems. The phosphoric-chromic acid stripping solution used reduced subsequent corrosion.

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Results at pH 7 to 8: Dichromate ion reduced attack to a satisfactory degree, as previously noted. In its absence, strong positive dependence of corrosion on temperature, pH and flow-rate were observed.

Film inhibitors such as Marathon lignin, No. 365, sodium acid pyrophosphate had only minor effects on the presence of 2 ppm $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot \text{H}_2\text{O}$.

Other Results on 2S Aluminum:- 50 ppm oxalic acid at pH's 3 to 4 caused high penetration rates (3 to 11 mils/mo) of aluminum at 70°C and 25 ft/sec flow rate, no local attack being apparent. Dichromate ion did not prevent this attack.

No effect due to changing solution oxygen contents from 0.1 to saturation at 80°C could be detected at pH 6.2 and 6.7, simulated River water, 20-25 ft/sec flow rate, no added peroxide.

There was found no additional danger of pitting due to temperature or peroxide concentration gradient or boiling under the conditions tested (essentially non-flowing, 10^{-4} N H_2O_2 , 2 ppm Cl^- , pH ~ 6).

Statistical tests to determine the probability of pitting attack failed because pitting did not occur, although it was believed that the solutions used would cause some pitting attack.

Coupling 2S aluminum to 304 stainless steel caused serious pitting attack of the aluminum at pH 6.5 as well as at 7.5, in the absence of dichromate. The addition of dichromate very much reduced the attack noted in its absence.

The Corrosion of Other Aluminum Alloys:- Sodium silicate (242 ppm SiO_2) was observed to prevent the rapid corrosion of alloy 17ST which was found at lower silica concentration in solutions containing 10^{-4} N H_2O_2 , ~ 80 ppm Na_3PO_4 at pH about 9, 95°C, 9 ft/sec flow rate.

The corrosion of alloys 52S and 61ST was very similar to that of 2S at 9 ft/sec flow rate, 1 ppm chloride, 70°C, 2×10^{-5} N H_2O_2 and at 35°C, no H_2O_2 , both at pH 6.5. Alloy 52S was also tested at pH 7.3, 2×10^{-5} N H_2O_2 , 70°. No pitting was observed and penetration was 0.2 mil/mo or less in all cases.

The cast alloys 360 and A-360 were observed to pit at pH 6.5, 23 ft/sec flow rate, 85°C, simulated River water, $1-2 \times 10^{-5}$ N H_2O_2 . Alloy A-360, containing less iron, pitted less severely than alloy 360. In similar solutions at pH 7.5 to 7.8, no pitting was observed. Comparison of the corruptions of the two alloys was difficult because of the difference in oxide coats formed. Penetration rates were of the order of 2 mils/mo or less.

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Alloy 72S was tested under several conditions at 20 to 25 ft/sec flow rate. Danger of pitting of 72S was more apparent for 72S than for 2S under all conditions tested. Weight changes of the two alloys under similar conditions were nearly the same. Experiments on alclad indicated that the protection of the 3S (no 2S available at the time) by 72S was dubious.

Recommendations:

From the corrosion tests run in this investigation, it is considered that 2S aluminum corrosion is slight enough so that the use of the material should be safe in Columbia River water at:

(a) pH 6 to 7, temperatures 70 to 95°C (and probably all lower temperatures) zero to 10^{-4} normal hydrogen peroxide, zero to 25 ft/sec flow rate, zero to 2 ppm chloride ion, with no other materials added to the water;

(b) pH 7 to 8, other conditions identical to (a) as long as 2 ppm $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ is present as a corrosion inhibitor.

The most danger of corrosion in cases (a) and (b) is believed due to local attack of the metal, causing penetration of the aluminum [cans or tubes]. Uniform penetration probably would usually be much less than, and never over 2 mils/mo.

It must be emphasized that this does not necessarily predict that 2S aluminum may be used according to plans at H.E.W. at the above conditions without any serious corrosion. No good simulation has been made of the effects of radiation and external factors such as the geometry or construction, presence of other construction materials, metal surface to solution volume ratio, etc. Tests nearer actual conditions should and have been made elsewhere.

A great deal of the value of this investigation has already been realized. 2S aluminum was chosen as slug coating and tubing material. Originally pH 6.5 was chosen for operation, but this figure was changed because of additional problems from the formation of hydrous oxide films in the corrosion testing units at Hanford.

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Approved by:

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INTRODUCTORY DISCUSSION

History of Testing Groups

With the formation of the coatings and Corrosion Group in the Chemistry Division in December, 1942 (J. P. Howe, Group Leader), the need for a rather large amount of information on the corrosion resistance of materials intended for construction was recognized. This group was transferred to the Metallurgy Section, Technical Division about March 1, 1943, it being recognized that the chief contribution offered by the group would be to the Technical Division. In October, 1943, the Group was divided into two, the Coatings Group and the Corrosion Group. In July, 1944 the Corrosion Section of the Technical Division was formed with the old Corrosion Group as a nucleus. From January through June, 1944, the program was authorized by number 124ML-54-4a; from July through November, 1944, 124ML-53-1.

As work progressed, and the use of aluminum as a protective coating became more certain, other corrosion groups were set up to test corrosion under conditions resembling actual operating conditions as closely as possible. The Engineering Development Section started such testing at Site B in July, 1943, this being a continuation of work previously started in April at the U. of C. power plant. CMX, the DuPont Corrosion Testing Group, began operations at Hanford, Washington, in October, 1943. Both of these groups used W geometry in their testing units, and CMX used actual W water.

Operating Conditions

The water-cooled plant uses aluminum tubes through which the cooling water flows over aluminum encased slugs. The use of alclad tubes was proposed and adopted, to prevent penetrating corrosion in the tubes and to reduce the corrosion of the canned slugs.

Causes Prompting Investigation

It was early recognized that slug coatings would be necessary to prevent the loss of by products into the water and to prevent corrosion of tuballoy, which is a very active metal. Considerable effort was therefore expended in forming and testing coatings of various types. Several metals were tested for their possible utility as coatings. Hydrogen peroxide was added to the testing solutions because it was known that H_2O_2 is formed in water under conditions of operation. It was recog-

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nized that this was not a good simulation of actual operating conditions in a plant but it was felt to be as good as was conveniently available for tests of long duration. Experiments simulating more closely actual conditions in the plant have been made by the Chemistry Division. Results are largely reported in CCL677. Results of the corrosion tests by this reporting group on various metals were issued in RUC-JPH-81, July 24, 1943. It may there be seen that aluminum offered the best resistance to corrosion of those tested. No other material was found which satisfied the three requirements of low danger coefficient, ease of fabrication and availability. Consequently, the major emphasis has been placed on aluminum. It was then necessary to determine the conditions which limit safe operation, using aluminum as a construction material. Probability of corrosion penetration had to be minimized in the presence of the water treatment process, and as far as possible, the effects of the plant itself. The studies here reported were undertaken with the object of determining these conditions by investigating the effects of all the known variables which might influence the corrosion behavior of aluminum in a water cooled plant at 1%. To this end a simulated water containing the major constituents of the actual water has been used, hereinafter referred to as simulated River water. This solution, though a fair approximation of the natural water, did not contain some constituents which it was recognized might exert more influence than suspected.

INVESTIGATION

Previous Knowledge of Aluminum Corrosion

There had been very little work done on the corrosion of aluminum under conditions of interest to the present application. The major part of the research done had been by the Aluminum Company of America and R. B. Sears, of their research staff, was early called upon as consultant for this investigation. None of their testing had been done in the presence of added hydrogen peroxide or the concentrations of interest and only a very limited amount in water of the general purity of that used in this investigation. The high solution flow rates here studied are considerably greater than those normally used in industry and very little had ever been done to evaluate its influence.

The specific effects of certain of the variables encountered were at least partially known. It had been shown that chloride ion and other halides have a harmful effect on the corrosion resistance of aluminum, but nearly all of the work had been done at concentrations considerably greater than that of interest here, the natural concentration in River water being about one half to two parts per million (this unit as used throughout this report is by weight). The effect of pH on aluminum corrosion in many types of solution was known. Aluminum is an

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amphoteric element and the metal will dissolve in either strongly acid or strongly alkaline solution, resulting in a strong dependence of corrosion rate on the pH of the corroding solution. It had been shown that the pH resulting in least aluminum corrosion is in the slightly acid range, about 6.5.

To understand the effect of solution flow rate it is necessary to consider the mechanism by which corrosion occurs. It had been shown that much of the natural corrosion of aluminum, especially in mildly acid solutions is electrolytic in nature, that is an electric current flows through the metal and, from certain anodic and cathodic areas, through the solution. At the anode the metal dissolves and at the cathode, dependent upon pH and other conditions, one of the chief reactions is the liberation of elementary hydrogen from the solution with the loss of electrons by the metal surface. The origins of such currents are discussed by Mears and Brown.¹ Briefly, three types of heterogeneities can be responsible: 1) in the solution (uneven mixing or local areas of poor circulation), 2) in the composition of the metal surface, such as at inclusions, etc, and 3) in the actual composition of the bulk metal at different places. The prevention of such corrosion can be accomplished by effective blocking or insulation of either the cathode or anode, or both, from the solution. Some of the preventers of reaction or "polarizers" are: (1) An aluminum oxide film, which is fairly impervious and prevents good mechanical contact between the ions of the solution and metal and thus protects it. The oxide is also a good electrical insulator, preventing the easy flow of current through it. It holds aluminum ions tightly and does not easily give them up to the solution (is relatively insoluble) with the result that the chief corrosion product is aluminum oxide. This sometimes forms the impervious film mentioned. (2) The hydrogen which is deposited at the cathode frequently effectively forms a film and insulates that area from contact with the solution, preventing further electrical action. (3) Other poorly conducting films prevent access of the ions in the solution to the metal surface. This includes corrosion inhibitors.

The rapid movement of the solution past the corroding surface can have several effects: 1) the natural protective oxide film may be swept away more rapidly than in static or slowly moving streams; 2) The hydrogen film which tends to protect the cathode may be swept away and its effect minimized; 3) the substances in the solution will have much better opportunity to exercise their effect on corrosion by better and more violent contact with the surface. Dissolved oxygen, for example, increases the tendency for anodic reaction and also removes the hydrogen film from the cathode, at the same time tending to provide a better protective oxide film; 4) where the product of the corrosion is other than solid aluminum oxide such as in acids and alkalis, rapid solution movement removes the products quickly, facilitating further reaction.

Increasing the temperature of the corroding solution decreased the stability of the hydrogen film on the cathode. In addition the nature of the corrosion product, aluminum oxide, may be changed. There are several forms of this material^{2/}, the alpha monohydrate being the stable product of corrosion from about 60-80°C to beyond 100°C in most dilute solutions.

Course Pursued in Study

Systems Used in Testing

The solutions used were stored in glass bottles on the floor above the testing laboratory and were fed into the systems through glass tubing with capillary constrictors to regulate the rate of replenishment. In most cases the rate of addition was such that calculated complete replacement was effected every four hours. In all cases the rate of addition was such that the solution composition remained constant within experimental error. The rates for the recirculating systems were about 8 cc/min at 70°C and 15 cc/min at 95°C. About 15 cc/min was used in the static beaker tests. The excess liquid was drained off by constant level siphons.

Solutions in the systems were analyzed for peroxide, chloride and pH twice each day; for calcium, magnesium and sulfate (when added) once a day. In the more recent tests conductivity has been measured.

Flowing systems are classified according to velocity of the solution across the test sample. The velocities used were 9, 15, 20-25 ft./sec. Figure 1 is a drawing of a 9 ft./sec. or 15 ft./sec. system. In these systems the heating was accomplished during the earlier stages of investigation by the use of gas flames, but this method did not allow easy control of temperature and was considered hazardous. In the newer systems, an electrical heating element was wrapped directly on the beaker which served as a solution reservoir. Control of heat was accomplished by a Variac (auto transformer) supplying the heating element. The pumps used in the 9 ft./sec. systems were Eastern Engineering Co. Model B pumps, and were constructed of monel metal. The pumps used in the 15 ft./sec. systems were Model E6, stainless steel, manufactured by the same company.

The speed of the pumps used in these systems was controlled by small auto transformers. Each system was calibrated by measuring the time taken to pump a known quantity of water through the system at measured readings of the manometer on the pump intake side, shown in Figure 1. A sample calculation of the calibration can be found in the appendix, page 109.

LIST OF MATERIAL

- ① SAMPLE TUBE 10mm ID PYREX
- ② MANOMETER
- ③ THERMOMETER
- ④ OVERFLOW
- ⑤ REPLENISH INLET
- ⑥ VARITRAN
- ⑦ EASTERN CENTRIFUGAL PUMP - MOD. B OR MOD E-6 STAINLESS STEEL
- ⑧ 1000 mm PYREX BEAKER
- ⑨ NICHROME WIRE HEATING UNIT
- ⑩ ASBESTOS INSULATION
- ⑪ GLASS SAMPLE HOLDER
- ⑫ RUBBER CONNECTOR

Figure 1

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CORROSION TESTING APPARATUS

METALLURGICAL PROJECT

P. B. AG Le Foucault

Usually three samples were suspended in the sample tubes with glass hooks. Samples remained in test from 300 to 600 hours duration unless the corrosion was of sufficient severity to warrant removal in a shorter time.

A diagram of the 20 ft./sec. system is given in Figure 2. The heaters used in this system were laboratory made and consisted of a suitable length of resistance wire coiled around a 1/8 inch mandrel, then drawn into a helical shape and inserted in a six to eight millimeter bent pyrex glass tube. The tube was then filled with dried powdered sil-ocel which acted as a heat transfer medium and prevented hot spots on the resistance coil. Two heaters were used in each system: one, always on, of 100 watts, and another, controlled by a relay, of 250 watts. The temperature was kept uniform by a bi-metallic thermo-regulator in conjunction with a thyatron relay which controlled the heater mentioned above. A diagram of this relay is given in the appendix, page lll .

An inverted glass T, of 5 mm glass tubing, was sealed into the bottom portion of the sample tube. The test samples were supported by the T and were separated by suitable lengths of glass tubing with spacers attached to assure centering. The top holder was a T sealed inside the upper tube in the proper position to hold the top sample. Four samples were used in each specimen tube but the upper sample, where solution boiling sometimes occurred, was not used in obtaining corrosion data. The velocity was measured as the water manometer reading across an orifice of tetrafluorethylene polymer. These systems were calibrated similarly to the 9 ft./sec. systems except that the flow rate was varied by varying the size of an additional orifice in the system.

Several series of tests were run with the object of determining the probability of pitting of corrosion specimens under conditions of chief interest and the influence of certain variables on this probability. The tests used about fifty samples each and the apparatus is shown in Figure A-0 (appendix). Aluminum or stainless steel propellers were used to force the solution past the samples at an estimated flow rate of several (about 3 to 5) ft /sec. The samples were held in place with heavy (1/8") 2S aluminum wire and were in contact with glass on both edges. The temperature was held constant in one case by immersing in a larger constant temperature water bath and in another by winding the beaker with resistance wire. In the latter case the voltage was controlled by a rheostat in series with the winding. Solutions were continually added through glass orifice tips or home-made glass flowmeters of the Rotameter type at a rate of about 5 cc/min.

- ① CONDENSER
- ② BI METALLIC THERMO REGULATOR
- ③ GLASS COVERED HEATERS 350°
- ④ OVERFLOW & THERMOMETER
- ⑤ MANOMETER
- ⑥ ORIFICE
- ⑦ 3 LITER RD BOTTOM PYREX FLASK
- ⑧ REPLENISHER INLET
- ⑨ 3/4 HP NASH CENTRIFUGAL PUMP
- ⑩ 29/42 $\frac{1}{8}$ JOINT
- ⑪ 19/38 $\frac{1}{8}$ JOINT
- ⑫ 29 mm PYREX TUBING
- ⑬ 50 mm PYREX TUBING
- ⑭ PYREX ELBOW 1
- ⑮ 10 mm ID PYREX SAMPLE TUBE
- ⑯ 5 mm TTUBE SAMPLE HOLDER
- ⑰ METAL FLANGE CLAMP
- ⑱ 32 mm PYREX TUBING
- ⑲ 34 mm PYREX TUBING

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PT-1	CORROSION TEST APPARATUS	
METALLURGICAL PROJECT	DRAWN	AG LE FEVRE

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A typical set-up in the static systems is shown in Figure 3. The samples used were 16 gauge material, 3 1/4" x 1 1/4". They were supported in a glass tube, totally immersed in a liter beaker and separated by short glass spacers. The solutions were mixed at the beaker from distilled water and stock solutions of sodium chloride and hydrogen peroxide. Capillary tips controlled the mixing rates of the stock solutions, using constant level float devices as in Figure 1. No other salts were added except dichromate, which was used in one series of tests. Heating was accomplished by exposed element hot plates, rated at 550 watts, with the supplied voltages controlled by Varitrans.

Samples

Some analyses of sample materials are available. Aluminum alloys 2S, 72S, 61ST, 52S, 17ST, were all obtained in the form of rolled sheet or of rod, all standard commercial alloys, prepared by the Aluminum Company of America. The 72S contained 1% Zn, and the other alloys analyzed showed compositions approximately those specified by the Aluminum Co.*

In the low flow rate systems the samples used were of 3/8" x 3" x 16" gauge material, rolled, 1/2 hard. A 1/8" hole near each end of the samples enabled them to be suspended in the solution with glass hooks. All surfaces were polished to give a smooth uniform finish. The following steps were used in surface preparation:

1. Polish on #1 emery paper.
2. Polish on #2-0 emery paper in direction opposite to that to Step 1.
3. Polish with 280 mesh silicon carbide - H₂O on canvas in direction opposite to that of Step 2.
4. Measure samples.
5. Clean with talc + H₂O and dry with Kleenex.
6. Put in desiccator under vacuum for 15 minutes before weighing.

Investigation showed that if 2S aluminum sample surfaces were reasonably smooth and uniform, a treatment with 5% sodium hydroxide followed by a 40% nitric acid wash, instead of polishing, did not result in any noticeable difference in the corrosion rate. Samples used in tests 178-180, 183, 184, 190-194 were not polished, but instead given the above mentioned caustic and nitric acid treatment. All others were given the mechanical pre-treatment.

* Analytical Section, MUC: 72SA1-11/22/43, 11/18/43 (spec. plate 2228); 61ST-11/27/43; 3S-12/8/43 (samp. no. 160, plate no. 2226); 2S-11/13/43 (plate no. 2226).

Figure 3

SYSTEM USED IN RUNNING STATIC CORROSION TESTS

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Figure 4

TWO TYPES OF GLASS CONSTANT LEVEL

SOLUTION SUPPLY DEVICES

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In the 20 ft./sec. systems the 1/2 hard-round samples were 1/4" in diameter x 2 1/2" long with knobs 1/8" in diameter x 1/2" in length on each end serving as supports. These samples were machined and then oil polished on a lathe with emery paper (#1, 0, 00, 000, 0000 used successively) measured, cleaned with talc and H₂O, dried with kleenex and then put in desiccator under vacuum for 15 minutes before weighing. Care was taken not to finger the samples. There had been some cases where attack was found due to finger prints.

The samples were removed from the recirculating systems twice a week for weighing. The procedure followed was to remove all samples, dry with kleenex, desiccate under vacuum for 15 minutes and then weigh. The average weight change for the three samples was obtained. At the completion of the test, the oxide coat was removed. The procedure used in the removal was to dip the samples in 40% HNO₃ at room temperature for 1 minute (to remove salts which may have been deposited) wash with distilled water, and immerse in a solution of 2% CrO₃ + 5% H₃PO₄ at 100°C. for 1/2 hour. This treatment removed the oxide corrosion product and only a negligible amount of metal (not more than 0.1 mg/sample). The solution was developed by the aluminum company². The value, over-all metal loss, was obtained from the initial and final sample weights, oxide free. In most cases the values here obtained are not the average of three measurements, only one sample being stripped of oxide. All samples were examined under the microscope and the number, depth, and width of the pits found are reported.

In the description of the samples after testing, all surface indentations less than .02 mm deep or .05 mm wide have been reported as mild roughness, moderate roughness or roughened surface, depending on the number of such indentations. Larger cavities have been measured and reported as pits.

The preparation of samples in statistical tests and static tests will be described under data and calculated results.

Solution Preparation

In all studies the solutions were made from distilled water with the direct addition of the various constituents. During the early stages of the program, the constituents were added directly to the test systems from concentrated stock solutions along with sufficient distilled water to give the desired concentrations. A constant head was held for delivery of solutions by means of constant level floats as shown in Figure 4. After the solution composition became complex and varied this method was discontinued for the recirculating systems, the last run for which it was used being No. 74. Starting with run 75, the solutions were made up with all the desired concentrations of the constituents included. A 12 gallon pyrex mixing bottle was used and the reagents were added to distilled water, stirred thoroughly,

and then distributed by siphon action to various glass reservoirs. Simulated River water used in all tests, unless otherwise specified, contained 20 ppm Ca^{++} , 6 ppm Mg^{++} , 90 ppm SO_4^{--} , 1 ppm Cl^- . These values approximated the concentrations in the actual River water except that the sulphate used was much higher than in the river. Other aluminum corrosion work indicates that sulfate has only a very minor effect, and for that reason calcium and magnesium ions were dissolved by adding them as sulfates. The appendix, page 110, gives the procedures used in preparing these solutions.

Chloride was obtained by adding CP NaCl to the water. Peroxide used was Merck's Superoxol, containing 30% hydrogen peroxide with no preservative. Reagent grade chemicals were used in making up all solutions. The simulated River water did not have added silica or the minor constituents such as Fe, Cu, Ni, and Cr. These are present in actual River water in small quantities, less than 0.2 ppm, and their influence was considered probably negligible. Potentially one of the most dangerous is Cu^{++} . Its effect was found unmeasurable at the concentrations used (see page 70). Conductivities of simulated River water samples ran consistently from 2 to 3×10^{-4} mho/cm, which compares exactly with those measured for several samples of actual River water. In some of the later studies 10-20 ppm SiO_2 was added to the water, the source being liquid sodium silicate, grade O in the first few runs, and crystals of CP sodium silicate (meta) in the remaining runs. Other inhibitors were also added in some of the special tests.

Data and Calculated Results

A. Corrosion of 2S Aluminum in Recirculating Systems

Complete data for all runs are given in the appendix. Wherever run numbers are used in tables, or elsewhere, in the body of the report, the corresponding run may be found in the appendix. The chart which precedes the runs may be used as an index to them. All pH values were measured at 30°C, regardless of the temperature used in the test.

It is felt by the authors that the combination of the measured data, weight, area and time into a unit such as $\mu\text{g}/\text{cm}^2/\text{hr}$ gives a satisfactory means of reporting any corrosion rate. However, combination of measured data with a constant such as the density of the material (giving average penetration rate) always infers to the authors that the person who measured the rate believed the resultant units to express legitimately the results of his test. For example, a reported corrosion rate in mils per month infers that it predicts a certain penetration which would be found at an average point on the surface, chosen at random. If this is not so, as when a rather large percentage of the total metal corrosion occurs at isolated pits, then it is felt that the unit should not be used to report the corrosion rate unless particular care is taken to point out the possibility of

misinterpretation. For this reason, corrosion rates on data sheets appended are always expressed in terms of micrograms per square centimeter per hour. No inference is intended that pitting never accounts for an appreciable fraction of the total corrosion. In nearly all cases measured at pH above 7, it is believed that the more easily usable units of penetration rate afford a sound method of reporting corrosion rate. To convert a rate in $\mu\text{g}/\text{cm}^2/\text{hr}$ to mils/month, it is necessary only to divide by 10, for aluminum.

Because it is felt to be the most useful single measure of corrosion where pitting is not serious, the slope of the uncleaned sample weight change curve for each run in the recirculating systems will be referred to hereinafter as the "corrosion rate" for that run. The data obtained from cleaned specimens will be referred to as the "rate of metal loss", which appears on the corrosion data sheets as "overall metal lost". A discussion of the relative value of the two kinds of data will be given later, under "Discussion of Results", page 89.

It is often difficult to determine with good accuracy the slopes of the weight change curves for uncleaned specimens, due to deviation of the points from a representative line drawn to express the data. It has been found that a great majority of these weight change curves become linear only after an initial period of non-linearity, during which a gain in weight or an unusually rapid weight loss is observed. This initial period was frequently observed to last up to about 250 hours of testing, and it is the slope of the curve beyond this time that is used in determining the "corrosion rate". Generally speaking, the less rapid the corrosion, the greater is the percent deviation of the points from any weight change curve which may be drawn. Partly for this reason, the reported corrosion rates can be expected to be in error by up to about 50% between values of 1 and about $0.3\mu\text{g}/\text{cm}^2/\text{hr}$ and by increasing amounts as the rate grows smaller. Often, good reproduction of values from samples in the same test is found; but, another test gives values of corrosion rate considerably different from the first. This method of determining corrosion rates sometimes fails at such low rates of attack because of irregular loss of fragments of corrosion product which weigh nearly as much as the total weight change to that time. The resultant loss in value of corrosion rates thus measured will be discussed later.

Other reasons for lack of reproducibility at small corrosion rates probably include small differences in sample surfaces. Such effects would not be particularly noticeable where corrosion is more severe because the surface metal soon corrodes away. In Table I are given several instances where check runs were made, sometimes due to difficulty in obtaining slightly different solution conditions. The

Table I

REPRODUCIBILITY OF CORROSION TESTS ON 2S ALUMINUM IN RECIRCULATING SYSTEMS

Solution: Simulated River Water

Run No.	pH	Temp., °C.	Flow Rate ft/sec.	H ₂ O ₂ Conc. Normality	Corrosion, µg/cm ² /hr.	
					Slope of Curve, Uncl. Specimens	Average Rate of Metal Loss
97	5.2	93	20	1x10 ⁻⁴	0.91	2.5
124	5.0	94	20	1x10 ⁻⁴	.69	1.44
94	5.4	95	9	1x10 ⁻⁴	.15	1.45
95	5.7	93	9	2x10 ⁻⁴	.6	2.49
108	6.1	70	9	1x10 ⁻⁴	.39	1.28
155	5.9	70	9	1x10 ⁻⁴	.41	.96
148	6.2	93	22	6x10 ⁻⁶	.11	.84
157	6.1	93	22	8x10 ⁻⁶	.23	2.3
140	6.5	70	9	1x10 ⁻⁵	.07	.07
141	6.7	70	9	1x10 ⁻⁵	.28	1.2
165	6.5	70	9	2x10 ⁻⁵	.10	.56
85	6.5	95	9	2x10 ⁻⁴	----	8.5
109	6.5	95	9	8x10 ⁻⁵	.5	2.2
110	6.7	95	9	8x10 ⁻⁵	.10	3.22
138	6.6	70	15	2x10 ⁻⁵	.39 or .22	.93
145	6.5	70	15	1x10 ⁻⁵	.17	1.1
159	6.7	70	15	1x10 ⁻⁵	.83	1.6
146	6.6	79	15	1x10 ⁻⁵	.78	1.1
160	6.7	80	15	1x10 ⁻⁵	.57	2.3
76	7.2	70	9	2x10 ⁻⁴	1.55	5.46
80	7.3	70	9	3x10 ⁻⁴	3.0	3.80

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type of variation in measured corrosion rates which may be expected is illustrated. It is indicated that for corrosion rates below about $1 \mu\text{g}/\text{cm}^2/\text{hr}$ ($0.1 \text{ mil}/\text{mo}$) about 50% accuracy in reproduction may be expected; when the rate is below about $0.2 \mu\text{g}/\text{cm}^2/\text{hr}$ it is nearly as much as the experimental reproducibility warrants to describe the rate merely as "less than 0.2 ".

EFFECT OF pH

Figures 5 and 6 show the effect of pH on the corrosion rate of 2S aluminum. In Figure 5 all runs were at 95°C and a solution flow rate of 9 ft/second. Most of the points in this figure are from runs in which the solution was simulated River water containing $10^{-4} \text{ N H}_2\text{O}_2$. The three points for which the solution base was only distilled water cannot be distinguished on the curve, indicating that the difference in corrosion rate between the two types of solution is negligible, at least at the pH values they were determined. These runs are numbers 36, 130 and 52, at pH 5.9, 6.7 and 6.8 respectively.

The values of pH used for the various runs are averages of values regularly measured. Variations from these averages sometimes were as high as 0.3 or 0.4 unit during the runs.

In Figures 5 and 6 are shown sharp rises in corrosion rate with decreasing pH below 4 to 4.5 and with increasing pH above about 7. The rates are quite low in the central parts of the curves, extending from about pH 4.5 to 7.0. A lack of reproducibility in these small corrosion rates is apparent and is the chief reason that the effects of certain variables on corrosion rate will be very difficult to observe, as discussed later under appropriate headings. The shapes of these curves appear to be essentially unaltered with differences in temperature and flow rate, although the pH values at which the rates become high at pH's near 4.5 and 7 are different for different conditions. These effects will be discussed later, under temperature and flow rate.

Pitting of sample surfaces during testing increased with decreasing pH at $\sim 1 \text{ ppm Cl}^-$. The effect generally first became noticeable somewhere near pH 5.5. At pH 4.0 and below, pitting was quite serious and this would certainly preclude the use of aluminum under these conditions. In Figure 7 are shown photographs of two runs at pH 3.2 and 3.4. From pH 5.5 to 7.0, pitting was observed only rarely, and above 7, never. At the latter condition, sample surfaces had a different appearance, only a general roughening being typical. Photographs of a typical run in the central pH range are shown in Figures 8 and 10; and of one at pH 7.5 in Figure 9.

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FIGURE 5

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FIGURE 6

S-49-24

25

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90

10 X

N H O	Velocity	ft/sec
221.4x10 ⁻⁴	9	
ppm Cl ⁻ 1.1	Temp., °C	93
pH 3.2	Hours in test	396
Water		
SIM. RIV. H ₂ O	S

RUN
98

10 X

N H O	Velocity	ft/sec
221.0x10 ⁻⁴	9	
ppm Cl ⁻ 1.3	Temp., °C	70
pH 3.4	Hours in test	404
Water		
SIM. RIVER		

Figure 7

2S Aluminum Samples After Test at Low pH

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26

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RUN
141
cleaned

10 X

100 X

N H O	Velocity	ft / sec
22.0 x 10 ⁻⁵	9	
ppm Cl ⁻ 1.1	Temp., °C	70
pH 6.7	Hours in test	409
Water		
S.M. RIVER		

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Figure 8

Cleaned 2S Aluminum Samples After Test, 10X and 100X

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RUN
77
cleaned

10 x

1.33 x

NH ₄ O	Velocity	9	ft/sec
221.4 x 10 ⁻⁴			
ppm Cl ⁻ 1.5	Temp., °C	95	
pH 7.5	Hours in test	401	
Water			
SIM. RIVER			

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Figure 9

2S Aluminum Samples After Test

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28

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RUN
141
un-
cleaned

10 X

1.33 X

N H O	Velocity	9	ft/sec
2260×10^{-5}			
ppm Cl ⁻	1.1	Temp., °C	70
pH	6.7	Hours in test	409
Water			
SLM. RIVER			

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Figure 10

2S Aluminum Samples After Test

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EFFECT OF TEMPERATURE

In simulated River water containing 10^{-5} to 10^{-4} N H_2O_2 , the effect of temperature on the corrosion rate of 2S aluminum is shown partially in Figure 6 at 9 ft/sec flow rate, pH below 4 and 7 to 7.5. From two tests at each temperature the corrosion rate was measured to be less at 95° than at 70°C at pH's about 3.3 and 4.0. (Runs 87, 88, 90, 98). Not enough data are available to really prove the point and it does not seem particularly important from an operational viewpoint. The conclusion is verified by the Engineering Development Section (see CT 2550) from similarly scanty evidence.

At pH 7.0 to 7.5 the corrosion rate is considerably greater at 95° than at 70°C, at 9 ft/sec flow rate in simulated River water. This is verified and given in considerably more detail by the Engineering Development Section in CE 973, for pH 7.5.

Data on corrosion rates at pH 6 to 7 are given in Table II at 70, 80 and 95°C. At 9 ft/sec, all comparisons indicate more rapid corrosion at 95°C than at 70°C. Figures 14 and 18 are photographs of runs at 9 ft/sec, with similar solutions at 70 and 95°C. At 15 and 23 ft/sec no definite temperature effect can be found. It appears that the higher velocities eliminate the effect noticed at 9 ft/sec. In the presence of 3 ppm Calgon, more rapid corrosion was obtained at 95° than at 70°C. Although the hydrogen peroxide concentrations were different at the two temperatures, the corrosion rate was increased considerably more by changing the temperature from 70 to 95°C (with a three fold H_2O_2 increase) than by increasing the $H_2O_2 \sim 10$ fold at 70°C.

EFFECT OF FLOW RATE

In Figure 6 the effect of flow rate on corrosion rate at pH below 4.5 and above 7 may be seen. In both cases, corrosion is considerably increased by higher flow rates. In both these pH ranges a good protecting oxide film does not form, and the rapid flow rate brings the corroding medium into better contact with the surface, sweeps away protecting hydrogen films and by its violence increases mechanical action or erosion.

In the pH range where there is a protecting film, the effect of solution velocity is difficult to determine. Table III lists those runs between pH 6 and 7 for which comparison can be made. It appears that at 70°C, corrosion is more severe at higher velocities, judging by corrosion rates and by the formation of pits on the sample surfaces. Photographs of samples of two such runs are shown in Figures 10 and 11. The same affect may be noticed to a lesser extent at 70°C. At

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Table II

EFFECT OF TEMPERATURE ON THE CORROSION OF 2S ALUMINUM

pH	Flow Rate ft/sec	Average H ₂ O ₂ Conc. Nx10 ⁵	Solution	Corrosion, $\mu\text{g}/\text{cm}^2/\text{hr}$								
				At 70°C			At 80°C			At 95°C		
				Slope of Curve Uncl. Spec.	Ave. Rate of Metal Loss	Run No.	Slope of Curve Uncl. Spec.	Ave. Rate of Metal Loss	Run No.	Slope of Curve Uncl. Spec.	Ave. Rate of Metal Loss	Run No.
5.9	15	0.2 (none added)	Sim River Water	0.20	0.56	120	0.2	0.69	121			
6.0	9	2	Dist.H ₂ O+2 ppm Cl ⁻	.29	.51	35				.43	1.78	36
6.0	9	2	Sim River Water	.42	.73	164				.60	2.090	122
6.2	23	0.8	Sim River Water	1.3	2.7	149				.11	.84	148
6.5	9	10	Sim River Water	.28	.84	154				----- .5	8.5 2.2	85
6.6	15	10	Sim River Water	.39 .17 .83	.93 1.1 1.6	138 145 159	.57 .78	2.3 1.1	160 146			
6.9	23	4	Sim River Water	.86	1.6	195	.86	1.5	196			
6.1 ^x	9	17 and 52 160	Dist.H ₂ O+1 ppm Cl ⁻	2.8 3.65	2.66 3.65	60 61				7.1	5.9	62

^oData unreliable due to uneven sample wear

^xContain 3 ppm Calgon

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Table III

EFFECT OF FLOW RATE ON THE CORROSION OF 2S ALUMINUM
Solution: Simulated River Water, Except Where Calgon Present

pH	Temp, °C	Average H ₂ O ₂ Conc. N x 10 ⁵	At 9 ft/sec				At 15 ft/sec				At 20-25 ft/sec			
			Corrosion, μg/cm ² /hr		Surface, Pits, and Roughness	Run No.	Corrosion, μg/cm ² /hr		Surface, Pits and Roughness	Run No.	Corrosion, μg/cm ² /hr		Surface, Pits and Roughness	Run No.
			Slope of Curve, Uncl. Spec.	Ave. Rate of Metal Loss			Slope of Curve, Uncl. Spec.	Ave. Rate of Metal Loss			Slope of Curve, Uncl. Spec.	Ave. Rate of Metal Loss		
5.3	70	2	0.42	0.73	None, mod. rough	164					1.3	2.7	Few	149
6.1	94	1	.68°	2.09°	Few	122					.11	.84	0, mod. rough	148
6.5	70	1.2	.07	.07	0, mild rough	140	.17	1.1	0, mild rough	145				
6.7		1	.28	1.2	0, mild rough	141	.83	1.6	Few	159				
6.6			.10	.56	0-mod. rough	165	.39	.93	0, mild rough	138				
6.6	79	1 to 2					.78	1.1	Few	146	.96	1.64	Numerous	133
							.57	2.3	Few	160				
6.2 ^x	69	3	2.4	2.5	Num, rough	59					5.0	5.1	0, mod. rough	72"
5.1 ^x	70	14	2.8	2.7	Num, rough	60					3.2	3.4	0, mod. rough	66"
6.1 ^x	70	130	3.7	3.7	Num, small	61					6.2	6.5	0, mod. rough	64

^oData unreliable due to uneven sample wear

^xContains 3 ppm Calgon distilled water, with 1 ppm chloride ion

Velocity 38 ft/sec

549 31

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RUN
159

10 X

1.33 X

N H O	Velocity	ft/sec
22 1.0×10^{-5}	15	
ppm Cl- 1.0	Temp., °C-	70
pH 6.7	Hours in test	397
Water		
SIM. RIVER		

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Figure 11

2S Aluminum Samples After Test

S-19-32

94°C, the reverse effect may be true. By the single comparison given, corrosion appears more rapid at 9 ft/sec than at 20-25 ft/sec, although it is to be noted that the corrosion rate determined at 9 ft/sec must be considered somewhat unreliable due to the unusual nature of the attack noted. One sample showed several large corroded or pitted areas. The other two showed only one or two spots of similar but much milder attack. The data used in Table III are only from the two samples showing the milder attack.

In a distilled water solution containing 1 ppm Cl^- , 3 ppm Calgon and hydrogen peroxide, the corrosion rates were higher at 24 to 38 ft/sec than at 9 ft/sec, although the surface roughening and pitting was greatly reduced at the higher flow rates. This effect was particularly noticeable at the lowest peroxide concentrations, $3 \times 10^{-5}\text{N}$. Photographs of the samples from these two runs are shown in Figure 12.

The general tendency is for increased flow rate to cause an increase in initial weight loss, followed by a steady rate lower than the initial rate. Where no Calgon was present, in Table III, all the 9 ft/sec runs showed either an initial gain in weight followed by a loss as the run progressed, or an initial weight loss which was not as rapid as the rate of loss later in the run. At 15 ft/sec all but one showed an initial rise, followed by a linear loss, and that one showed an initial fast weight loss. At 20 to 25 ft/sec two runs showed an early rapid sample weight loss and the other showed an initial loss less rapid than the later constant rate.

EFFECT OF CHLORIDE ION

In Table IV are presented data showing the effect of chloride ion on the corrosion of 2S aluminum at 9 ft/sec solution flow rate, with H_2O_2 but no additional electrolytes present. In the absence of Calgon increasing the amount of chloride ion present from zero to 6 ppm increased the attack very much at 95°C, as shown in Table IV and Figures 17 through 21. At 70°C, the corrosion rates do not show particularly well the type of corrosion which began to show up at higher chloride

34

~~SECRET~~ RUN
72

10 X

N H O	Velocity	ft/sec
221.2 x 10 ⁻⁵	38	
ppm Cl ⁻ 1.2	Temp., °C-	68
pH 6.2	Hours in test	407
DIST. Water

RUN
59

10 X

N H O	Velocity	ft/sec
224.3 x 10 ⁻⁵	9	
ppm Cl ⁻ 1.0	Temp., °C-	70
pH 6.2	Hours in test	421
DIST. Water		

Figure 12

2S Aluminum Samples After Test
Influence of Flow Rate, Calgon Present

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Table IV

EFFECT OF CHLORIDE ON THE CORROSION OF 2S ALUMINUM
Flow Rate - 9 ft/sec

Run No.	Cl ⁻ , ppm	pH	Temp. °C	H ₂ O ₂ , N x 10 ⁵	Corrosion Rate, µg/cm ² /hr		Surface Pits and Roughness
					Slope of Curve, Uncleaned Spec.	Ave. Rate of Metal Loss	
33	0	5.8	70	1.2	0.08	0.61	None, rough
35	2.0	6.1	70	2.8	.29	.51	Few, dull surface
37	3.8	6.0	70	4.2	-1.28 (gain)	4.6	Few, rough
39	5.5	5.9	70	2.1	-.06 (gain)	1.30	Several rough areas
34	0	6.0	95	1.6	-.08 (gain)	.28	None, rough
36	2.1	5.9	95	1.4	0.3	1.78	Several, rough
38	3.9	6.0	95	1.8	-.16 (gain)	.72	Several, rough
40	6.1	5.9	95	3.1	-4.5 (gain)	21.0	Very rough, W. small pits
41 ^o	12.0	6.1	94	1.0	9.71	37.5	Very rough, pitted
59 ^x	1.0	6.2	70	4.3	2.4	2.47	Many, rough
68 ^x	2.4	6.2	68	2.8	3	6.77	Many, rough
46 ^x	4.1	6.2	70	1.3	28	14.9	Very rough, pitted
63 ^x	2.6	6.0	94	10	1	7.9	Rough, pitted
45 ^x	4.1	6.1	95	9.4	13	25	Very rough, pi Hed

^oAluminum alloy 174 used

^x3ppm Calgon present

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36

~~SECRET~~ 10 X
un-
cleaned

N H O	Velocity	ft/sec
221.2 x 10 ⁻⁵	9	
ppm Cl ⁻ 0	Temp., °C	70
pH 5.8	Hours in test	605
DIST. Water		

RUN
33 10 X
cleaned

N H O	Velocity	ft/sec
221.2 x 10 ⁻⁵	9	
ppm Cl ⁻ 0	Temp., °C	70
pH 5.8	Hours in test	605
DIST. Water		

Figure 13

2S Aluminum Samples After Test

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37

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10 x
Un-
cleaned

N H O	Velocity	ft/sec
22.8x10 ⁻⁵	9	
ppm Cl ⁻ 2.0	Temp., °C	70
pH 6.1	Hours in test	905
DIST. Water		

RUN
35

10 x
cleaned

N H O	Velocity	ft/sec
22.8x10 ⁻⁵	9	
ppm Cl ⁻ 2.0	Temp., °C	70
pH 6.1	Hours in test	905
DIST. Water		

Figure 14

2S Aluminum Samples After Test

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38

~~SECRET~~ 10 x
un-
cleaned

N H O	Velocity	ft/sec
224.2×10^{-5}	9	
ppm Cl ⁻ 3.8	Temp., °C-	70
pH 6.0	Hours in test	173
DIST. Water		

RUN
37 10 x
cleaned

N H O	Velocity	ft/sec
224.2×10^{-5}	9	
ppm Cl ⁻ 3.8	Temp., °C-	70
pH 6.0	Hours in test	173
DIST. Water		

Figure 15

2S Aluminum Samples After Test

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S-49-38

39

~~SECRET~~ 10 x
un-
cleaned

N H O	Velocity	ft/sec
22.1 x 10 ⁻⁵	9	
ppm Cl ⁻ 5.5	Temp., °C	70
pH 5.9	Hours in test	524
DIST. Water		

RUN
39 10 x
cleaned

N H O	Velocity	ft/sec
22.1 x 10 ⁻⁵	9	
ppm Cl ⁻ 5.5	Temp., °C	70
pH 5.9	Hours in test	524
DIST. Water		

Figure 16

2S Aluminum Samples After Test

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40

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RUN
34

10 X

1.33 X

N H O	Velocity	ft/sec
22.16 x 10 ⁻⁵	9	
ppm Cl ⁻ 0	Temp., °C	95
pH 6.0	Hours in test	685
DIST. Water		

Figure 17

2S Aluminum Samples After Test

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41

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RUN
36

10 X

1.33 X

N H O	Velocity	ft/sec
22.4×10^{-5}	9	
ppm Cl ⁻ 2.1	Temp., °C-	95
pH 5.9	Hours in test	656
DIST. Water		

Figure 18

2S Aluminum Samples After Test

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42

~~SECRET~~

RUN
38

10 X

1.33 X

N H O	Velocity	ft/sec
221.8x10 ⁻⁵	9	
ppm Cl ⁻ 3.9	Temp., °C-	95
pH 6.0	Hours in test	681
DIST. Water		

Figure 19

2S Aluminum Samples After Test

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43

~~SECRET~~ RUN
40

10 X

1.33 X

N H O	Velocity	ft/sec
22 3.1×10^{-5}	7	
ppm Cl ⁻ 6.1	Temp., °C-	95
pH 5.9	Hours in test	222
DIST. Water		

Figure 20

2S Aluminum Samples After Test

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S-49-43

44

~~SECRET~~ RUN
41

10 X

1.33 X

N H O	Velocity	ft/sec
22	1.0×10^{-4}	9
ppm Cl ⁻	12.0	Temp., °C- 94
pH 6.1	Hours in test	177
DIST. Water		

Figure 21

175 Aluminum Samples After Test

S-49-44

concentrations. Figures 13 through 16 are photographs showing samples after corrosion, with the corrosion product on and with it removed. The tendency for increasing amounts of pitting is apparent at 4 and 6 ppm Cl^- .

In the presence of 3 ppm Calgon, chloride attack is considerably increased. When the chloride concentration was 4 ppm, very severe corrosion occurred, both at 70 and 95°C, as seen in Figure 22 and Table IV. A photograph of the run with 1 ppm Cl^- present at 70°C is shown in Figure 12, Run 59.

In general, the presence of chloride ion in the solution causes the formation of a more adherent corrosion product, which is at the same time less preventive of subsequent corrosion. It is typical for weight change curves of samples in such solutions to show a rapid initial increase followed by a slower rate of weight gain, or by a weight loss when the reaction is rapid enough to cause the formation of large quantities of corrosion product which is swept off. The effect of chloride ion in the absence of peroxide has not been investigated.

EFFECT OF HYDROGEN PEROXIDE

Runs which show the effect of hydrogen peroxide on the corrosion of 2S aluminum are given in Table V. In distilled water, the effect of a small concentration of H_2O_2 was to increase the corrosion rate at 80°C, 25 ft/sec flow rate, pH 6.1. It will be noted that in all cases where no H_2O_2 was added to the test solution, it was generated during the reaction to a concentration of 1 to 3×10^{-6} N, under the conditions of the tests. This is in agreement with the previously reported formation of peroxide by the water corrosion of aluminum.⁴

Runs in simulated River water at pH about 6.0 indicate similar increase in corrosion rate with increasing H_2O_2 concentration at 22 ft/sec, 93°C and somewhat less so at 15 ft/sec, 80°C. In simulated River water, 9 ft/sec, 70°C, pH 6 and 6.5 no consistent effect due to increasing concentrations of H_2O_2 could be detected.

EFFECT OF INHIBITORS AND OTHER ADDITIVES

Calgon: This material is a commercial corrosion inhibitor, "sodium hexa-metaphosphate", which has been found useful for preventing the corrosion of iron and was recommended by the manufacturer as a possible inhibitor for aluminum corrosion. A large number of runs were made with this material present and in nearly every case the corrosion was markedly increased. Data from several such runs are presented in Table VI, with some containing no Calgon, for comparison.

46

~~SECRET~~ RUN
46

10 X

N H O	Velocity	ft/sec
221.3x10 ⁻⁵	9	
ppm Cl ⁻ 4.1	Temp., °C-	70
pH 6.2	Hours in test	320
DIST. Water	3.7 ppm Calgon

RUN
68

10 X

N H O	Velocity	ft/sec
222.8x10 ⁻⁵	9	
ppm Cl ⁻ 2.4	Temp., °C-	68
pH 6.2	Hours in test	370
DIST. Water	3.3 ppm Calgon	

Figure 22

2S Aluminum Samples After Test
Chloride Effect, Calgon Present

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S-49-46

Table V

EFFECT OF HYDROGEN PEROXIDE ON THE CORROSION OF 2S ALUMINUM

Run No.	H ₂ O ₂ Conc. N x 10 ⁵	Flow Rate ft/sec	Temp. °C	pH	Solution	Corrosion Rate, µg/cm ² /hr		Surface Pits and Roughness
						Slope of Curve Uncl. Spec.	Ave. rate of Metal Loss	
136	0.1 ^a	22	80	6.1	Dist. water	.16	.3	0, mild rough
48	0.5	28	80	6.1	Dist. water	.86	1.34	0, smooth
148	0.6	22	93	6.2	Sim River	.11	.84	0, mod rough
157	8	22	93	6.1	Sim River	.23	2.3	0, mod rough
122	0.1 ^a	15	80	5.9	Sim River	.2	.69	0, mod rough
115	11	15	80	5.9	Sim River	.25	2.39	0, mod rough
163	0.3 ^a	9	70	6.3	Sim River	0.31	0.68	0, mod rough
164	2.8	9	70	6.0	Sim River	.42	.73	0, mod rough
108	12	9	70	6.1	Sim River	.39	1.28	0, mod rough
155	12	9	70	5.9	Sim River	.41	.96	Few
153	0.1 ^a	9	70	6.5	Sim River	.44	1.06	0, slight rough
140	1	9	70	6.5	Sim River	.07	.07	0, mild rough
141	1	9	70	6.7	Sim River	.28	1.2	0, mod rough
165	2.2	9	70	6.5	Sim River	.10	.56	0, mod rough
154	11	9	70	6.5	Sim River	.28	.84	0, mod rough
59 ^o	4.3	9	70	6.2	Dist. + 1 ppm Cl ⁻	2.4	2.47	Num, rough
60 ^o	17	9	70	6.2	Dist. + 1 ppm Cl ⁻	2.8	2.66	Num, rough
61 ^o	160	9	70	6.1	Dist. + 1 ppm Cl ⁻	3.65	3.65	Num, rough

^aNo H₂O₂ added to the test. This much generated by corrosion reaction.

^o3 ppm Calgon present

8-49-67

Table VI

EFFECT OF CALGON ON CORROSION OF 2S ALUMINUM IN RECIRCULATING SYSTEMS
Solution Base: Distilled Water

Run No.	Calgon ppm	pH	Flow Rate ft/sec	Temp °C	Chloride ppm	H ₂ O ₂ Conc Nrl0 ⁵	Corrosion, µg/cm/hr		Surface Pits and Roughness
							Slope of Curve Uncl. Spec.	Ave. Rate of Metal Loss	
35	0	6.1	9	70	2.0	2.8	-0.29 (gain)	0.51	Few, mod rough
68	3.3	6.2	9	68	2.4	2.8	3.0	0.77	Num, rough
37	0	6.0	9	70	3.8	4.2	-1.28 (gain)	4.6	Num, rough
46	3.2	6.2	9	70	4.1	1.3	1.3	14.9	Badly corroded
38	0	6.0	9	95	3.9	1.8	ind.	.72	Num, rough
45	3.0	6.1	9	95	4.1	9.4	13	35	Badly corroded
40	0	5.9	7	95	6.1	3.1	-4.5 (gain)	24.0	Num, rough
44	11.4	6.5	9	95	5.9	7.3	22.2	61	Badly corroded
66	3.5	6.1	38	72	1.3	11	3.2	3.35	0, mod rough
59	3.1	6.2	9	70	1.0	4.3	2.4	2.47	Num, rough
72	4.0	6.2	38	68	1.2	1.2	5.0	5.05	0, smooth

86-64-48

Photographs of some samples after corrosion by Calgon-containing solutions are given in Figures 12, 22 and 23.

The runs containing Calgon were usually characterized by nearly linear weight change curves for uncleaned samples, except where chloride ion was somewhat high (about 4 ppm or above), in which case the usual effect (for chloride) of an initial weight gain, followed by a loss, was observed. The large amount of white material that formed on sample surface (see Figures 22 and 23) had a different appearance from that of the normal aluminum oxide corrosion product. It was not analyzed but probably contained phosphate. Runs 106 and 107 (not in Table VI; see appendix) were made at 79°C, 15 ft/sec flow rate, 3 ppm Calgon, dilute H_2O_2 , in simulated River water. The effect of the Calgon there is not easy to interpret. The samples contained none of the very large pits commonly associated with this material, probably because of the high pH (8.3). Sample wear or erosion was rapid, but there are no runs without Calgon to serve as comparisons. The influence of the presence of calcium and magnesium ions in these solutions on the Calgon effect similarly cannot be told.

The difference in the effect of Calgon at different velocities has previously been noted (Figure 12). At ~ 20 -25 ft/sec flow rate no serious pitting was noticed in any case. At 9 ft/sec flow rate the pitting attack is much more noticeable at $\sim 10^{-5}$ N peroxide than at $\sim 10^{-3}$ N. These runs are listed in Table III.

Dichromate Ion: The use of an effective corrosion inhibitor was considered desirable in plant application, where the pH of the water of most interest would be somewhat above 7.5 and where dissolved silica would be present. In this instance the corrosion of 2S aluminum in straight River water was known at pH values between 7.5 and 8.0 and interest was largely centered on behavior in the presence of 2 ppm $Na_2Cr_2O_7 \cdot 2H_2O$, the inhibitor proposed for use in plant operation. For this reason, very few blank runs were made under conditions equivalent to those of the dichromate-containing runs. In Table VII are given the data from runs in which dichromate was present with no unusual additives other than silica, added as sodium silicate.

It will be seen that at pH above 7, corrosion was never particularly dangerous when dichromate was present, because deep areas of local attack were not encountered. This is true when silica was present and even in the presence of 2 ppm Calgon at 95°C, 9 ft/sec, pH 8.1, as in Run 194 (not given in Table VII). Figures 24 through 26 show the improvement in sample surfaces after corrosion by the addition of increasing amounts of dichromate. Attack by the blank solution of sodium silicate was quite apparent. There is some indication that as the pH is increased near 8, in the presence of dichromate or dichromate and silica, the corrosion rate is reduced. The roughness of the sample

50

~~SECRET~~ RUN
44

10 X

1.33 X

N H O	Velocity	ft/sec
22.73 X 10 ⁻⁵	9	
ppm Cl ⁻ 5.9	Temp., °C-	95
pH 6.5	Hours in test	365
DIST. Water	11.4 ppm Calgon	

Figure 23

2S Aluminum Samples After Test

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S-49-50

Table VII

EFFECT OF DICHROMATE ON CORROSION OF 2S ALUMINUM AT 20-25 ft/sec FLOW RATE
Solution Base: Simulated River Water

Run No.	Na ₂ Cr ₂ O ₇ · 2H ₂ O, ppm	pH	Temp, °C	H ₂ O ₂ Conc, N×10 ³	SiO ₂ , ppm	Corrosion μg/cm ² /hr		Surface Pits and Roughness
						Slope of Curve, Uncl. Spec.	Ave. Rate of Metal Loss	
192 ^o	2.2	8.5	95	10	12.8	-1.75 (gain)	0.68	0, mod. rough
172	2.1 ^x	8.4	80	14	0	1.3	1.6	
167	1.0 ^x	7.8	80	12	0	3.9	15.4	0, mod. rough
187	0	8.1	95	1	8.2	1.95	5.5	0, mild rough
173	2.5	7.8	95	16	7.5	11.1	18.9	0, mod. rough
174	4.8	8.1	95	27	8.6	.58	3.2	0, rough
175	8.4	7.9	95	31	8.9	.59	2.5	0, rough
176	17.0	7.6	95	51	7.5	1.1	2.8	0, rough
151	2.5	5.5	80	11	0	.87	.96	0, mild rough
152	5.9	5.5	80	12	0	1.9	1.7	Few, rough
150	2.3	4.5	80	8	0	.38	.48	0, v. sl. rough
177	4.8	3.4	95	8	0	116	101	0, very rough
181	2	2.0	95	1	10	530	530	0, very rough
182	8	2.0	95	1	10	544	544	0, very rough

^oVelocity 9 ft/sec

^xK₂Cr₂O₇ used instead of Na₂Cr₂O₇ · 2H₂O. The molecular weights are almost the same (294 and 298).

8-47-51

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52

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RUN

187

10 X

N H O	Velocity	22	ft/sec
22	1.0×10^{-5}		
ppm Cl ⁻	1.0	Temp., °C	95
pH	3.1	Hours in test	300
Water			
SIM. RIVER	8.2 ppm	SiO ₂

RUN

173

10 X

N H O	Velocity	25	ft/sec
22	1.6×10^{-4}		
ppm Cl ⁻	1.0	Temp., °C	95
pH	7.8	Hours in test	300
Water			
SIM. RIVER	7.5 ppm	SiO ₂	
	2.5 ppm	Na ₂ CO ₃ · 2H ₂ O	

Figure 24

2S Aluminum Samples After Test

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S-49-52

53

~~SECRET~~ RUN
175

10 x

N H O	Velocity	ft/sec
223.1X10 ⁻⁴	22	
ppm Cl ⁻ 1.1	Temp., °C-	95
pH 7.9	Hours in test	300
Water	8.9 ppm SiO ₂	
SIM. RIVER	84 ppm Na ₂ Cr ₂ O ₇ · 2H ₂ O

RUN
174

10 x

N H O	Velocity	ft/sec
222.7X10 ⁻⁴	22	
ppm Cl ⁻ 1.2	Temp., °C-	95
pH 8.1	Hours in test	300
Water	8.6 ppm SiO ₂	
SIM. RIVER	4.8 ppm Na ₂ Cr ₂ O ₇ · 2H ₂ O	

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Figure 25

2S Aluminum Samples After Test

S-49-53

54

~~SECRET~~ RUN
176

10 X

N H O	Velocity	ft/sec
22.51 X 10 ⁻⁴	25	
ppm Cl ⁻ 1.1	Temp., °C-	95
pH 7.6	Hours in test	300
Water	7.5 ppm SiO ₂	
SIM. RIVER	17.0 ppm Na ₂ CO ₃ · 2H ₂ O

RUN
167

10 X

N H O	Velocity	ft/sec
22.12 X 10 ⁻⁴	22	
ppm Cl ⁻ 1.1	Temp., °C-	80
pH 7.8	Hours in test	314
Water	1.0 ppm K ₂ Cr ₂ O ₇ · 2H ₂ O	
SIM. RIVER		

Figure 26

2S Aluminum Samples After Test

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S-49-54

surfaces does not always correlate particularly well with the corrosion rates or rates of metal loss measured. Probably the criterion of suitability for the use of aluminum as a corrosion resistant material under such conditions should be similar to that at pH near 6.5 without dichromate; namely, that no local attack which offers danger of penetrating thin aluminum construction parts should appear.

In the lower pH range, below 6, dichromate seems to be less effective as an inhibitor. At pH 5.5, for example, no appreciable corrosion was observed when the solution contained 2.5 ppm sodium dichromate, but definite pitting attack appeared when the solution contained 5.9 ppm sodium dichromate. It is not considered a sound practice to form judgments on a single test, but the evidence points to some harm being caused by increasing the dichromate concentration as in these runs (151 and 152). At pH 3.4 and below, no reduction in corrosion rate of the aluminum by dichromate was discernible.

Dissolved Silica: Since silica is present in natural River water and might also be added, its effect on the corrosion of 2S aluminum is of particular interest. In Table VIII are listed some runs made in which there was added no other substance which it was believed would influence aluminum corrosion. The conclusion is that silica, from 4 to 10 ppm, causes an increase in the corrosion rate, but not in dangerous localized attack or pitting. The increased attack is illustrated by Figure 27, where samples of Runs 77 and 134 are photographed. The small difference in the chloride concentration in these runs (0.8 and 1.5) would not be expected to cause appreciable difference in corrosion.

Three runs, each of which contained 2 ppm sodium dichromate and 6-12 ppm SiO_2 at pH 8.0 to 8.5, show an unusual effect. In each case the amount of aluminum oxide monohydrate (the most likely product of corrosion²) formed by the quantity of metal corroded as determined from cleaned sample weights, was less than the weight of the coat found on the sample at the end of the run. The conclusion drawn is that the coat contained some silica, chromium, and/or Calgon and pyrophosphate which last two were added in Runs 194 and 193, respectively.

Run No.	Aluminum Corroded, mg/cm^2	Calculated $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$ formed, mg/cm^2	Wt. of Coat found mg/cm^2
192	0.194	0.43	0.66
193	.042	.09	.36
194	.054	.12	.45
77	6.34	17.6	4.42

The case cannot be proved in this way for any other runs, and an example of the usual relationships are given by Run 77.

Table VIII

THE EFFECT OF DISSOLVED SILICA ON THE CORROSION OF 2S ALUMINUM IN RECIRCULATING SYSTEMS
Solution Base: Simulated River Water

Run No.	SiO ₂ , ppm	pH	Flow Rate ft/sec	Temp., °C	H ₂ O ₂ Conc. N x 10 ⁵	Corrosion, µg/cm ² /hr		Surface Pits and Roughness
						Slope of Curve, Uncl. Spec.	Ave. Rate of Metal Loss	
142	0	6.9	9	94	0.6	1.2	6.3	0, mod. rough
132	2.5	6.7	9	93	2	~1.5	4.8	0, mod. rough
133	4.7	6.7	9	93	1.7	1.6	10.9	0, mod. rough
134	8.6	7.4	9	94	2.8	17.5	21.6	0, very rough
77 ^x	0	7.5	9	95	14	4.25	15.8	0, rough
137	5.2	7.1	15	80	1.7	2.7	7.6	0, rough
187	8.2	8.1	22	95	1	2.0	5.5	0, mild rough

^xSim River Water contains only 3 ppmCa⁺⁺, 2 ppmMg⁺⁺

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57

~~SECRET~~ RUN
134

10 X

N H O	Velocity	ft/sec
222.8x10 ⁻⁵	9	
ppm Cl ⁻ 0.8	Temp., °C-	94
pH 7.4	Hours in test	402
Water	8.6 PPM SiO ₂	
SIM. RIVER

RUN
77
un-
cleaned

10 X

N H O	Velocity	ft/sec
221.4x10 ⁻⁴	9	
ppm Cl ⁻ 1.5	Temp., °C-	95
pH 7.5	Hours in test	401
Water		
SIM. RIVER		

Figure 27

28 Aluminum Samples After Test

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Calcium, Magnesium and Sulfate Ions: Calcium and magnesium sulfates and sodium chloride were added to distilled water to give "simulated River water"; the procedure is described in the Appendix, page 110. In Figure 6 the runs made in simulated River water cannot be distinguished from those in distilled water, as has previously been pointed out, page 22. Table IX contains some direct comparisons of runs made in the solution bases used (distilled water and simulated River water). Outside of the specific effects of the three ions calcium, magnesium and sulfate, which are believed to be negligible, the chief influence of the simulated River water would be its increased conductivity. Typical distilled water solutions at pH ~ 6 , 1 ppm Cl^- , 10^{-4} to 10^{-5} N H_2O_2 were measured to have a conductivity of $\sim 6 \times 10^{-6}$ mho/cm, while simulated River water consistently gave values of 2 to 3×10^{-4} mho/cm in the same pH range. Conductivities of distilled water solutions as above at pH 5 had a conductivity of 1×10^{-5} mho/cm.

Corrosion rates and sample appearances checked well between distilled water and simulated River water for the first two comparisons. In the last two comparisons, checks were not as good, but reproduction of conditions was not as good, especially as regards solution flow rate. In general there is very little difference in the corrosion behavior of 2S aluminum in distilled water solutions and simulated River water solutions under the conditions tested.

Sodium Nitrate and Sodium Nitrite: In searching for an effective corrosion inhibitor 200 ppm sodium nitrate was added to the corroding solution in Run 43. In Table X are given the runs in which nitrate and nitrite were used as possible inhibitors. When the solution contained 200 ppm NaNO_3 good protection was observed from the areas of local attack noted in the solution (4 ppm Cl^-) in the absence of inhibitors, as is shown by Figures 19 and 28, Runs 38 and 43. A series of three runs was made at pH about 7.2, in the presence of dissolved silica. No improvement of sample smoothness was noticed, although 9 and 14.5 ppm NaNO_3 seem to have caused about a 50% reduction in corrosion rate. These conditions are not conducive to pitting. The roughened surfaces noted are probably attributable to the silica present.

Runs 54 and 67 were made to test the inhibition offered by about 24 ppm sodium nitrate in the presence of 3 ppm Calgon. No blank run was made at 15 ft/sec. Similar conditions at 9 ft/sec flow rate caused severe pitting, while at 38 ft/sec no serious pitting was observed. It is therefore impossible to be certain that absence of pitting observed at 15 ft/sec flow rate was due to the sodium nitrate present.

Table IX

EFFECT OF CALCIUM AND MAGNESIUM SULFATES ON THE CORROSION OF 2S ALUMINUM IN DISTILLED WATER SOLUTIONS
All Distilled Water Solutions Contained 1ppm Cl^-

Run No.	Solution Base	pH	Flow Rate ft/sec	Temp., °C	H_2O_2 Conc., $N \times 10^5$	Corrosion, $\mu\text{g}/\text{cm}^2/\text{hr}$		Surface Pits and Roughness
						Slope of Curve, Uncl. Spec.	Ave. Rate of Metal Loss	
130	Dist. H_2O^x	6.7	9	94	1.5	.12	2.3	0, mod. rough
125	Sim. Riv. ^x	6.6	9	94	2.9	.16	1.52	0, mod. rough
55	Dist. H_2O	6.0	15	80	51	.24	.79	Few, mild rough
115	Sim. Riv.	5.9	15	80	11	.25	2.39	0, mod. rough
56	Dist. H_2O	5.9	39	79	15	.9	.41	Few, mild rough
144	Sim. Riv.	6.2	20	80	8	.42	.9	Few/small, mild rough
49	Dist. H_2O	6.8	38	82	2.4	.23	.95	Few/small mod rough
113	Sim. Riv.	6.6	20	79	2	.96	1.64	Num., rough

^x $\text{Cl}^- = 0$ ppm

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8-49-59

Table I

CORROSION INHIBITION OF 2S ALUMINUM BY SODIUM NITRATE AND SODIUM NITRITE

Run No.	Sodium Nitrate or Nitrite ppm	Solution Base	pH	Flow Rate ft/sec	Temp. °C	H ₂ O ₂ Conc. N x 10 ⁵	Corrosion, µg/cm ² /hr		Surface Pits and Roughness
							Slope of Curve, Uncl. Spec.	Ave. Rate of Metal Loss	
Nitrate									
38	0	Dist. H ₂ O plus	6.0	9	95	1.8	Indet.	.72	Roughened
42	200	3.9ppm Cl ⁻	6.1	9	95	6	1.2	1.00	corroded areas
69	3.5	Sim River	7.2	15	70	2.7	13.7	12.2	None, very rough
183	9.2	H ₂ O plus	7.2	15	70	1	5.5	7.5	None, very rough
170	14.5	6.9 to 8.4 ppm SiO ₂	7.1	15	70	3.1	6.5	10.9	None, very rough
54 ^x	24	Dist. H ₂ O +2.2ppm Cl ⁻ +2.9ppm Calgon	6.1	15	80	47	6.1	3.33	None, rough
67	23	Dist. H ₂ O +2.2ppm Cl ⁻ +3.1ppm Calgon	6.0	15	79	59	5.6	5.9	None, rough
Nitrite									
190	3.0	Sim River H ₂ O plus	7.5	15	70	1	16.0	18.2	None, mod. rough
191	6.0	7.0 to 8.8	7.6	15	70	1	14.0	15.9	None, mild rough
184	14.0	ppm SiO ₂	7.2	15	70	1	7.3	6.6	None, mod. rough

^x Sample surfaces anodized before testing: 30 minutes as anode in 15% H₂SO₄ at 15V, 30-35°C; then 30 minutes in boiling distilled water (no electrical connections). This coat lasted visibly for the first 200-250 hours of the test. By that time most of it had worn off and apparently corrosion was then normal for aluminum not protected by such an oxide coat.

2-49-60

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RUN

43

10 X

1.33 X

N H O	Velocity	ft/sec
22.60X10 ⁻⁵	9	
ppm Cl ⁻ 3.9	Temp., °C-	95
pH 6.1	Hours in test	559
DIST. Water	200 ppm NaNO ₃	

Figure 28

2S Aluminum Samples After Test

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8-49-61

When sodium nitrite was added to a silica containing solution similar to that used with sodium nitrate, no improvement in surface condition was noticed. A reduction in corrosion rate seems to have occurred when 14 ppm NaNO_2 was used. Although the pH was lower than in Runs 190 and 191, it was the same as in the runs where NaNO_3 was added to the solution.

In general, both sodium nitrate and nitrite seem to be corrosion inhibitors under the conditions tested, but neither is more than moderately effective, while requiring rather high concentrations compared to effective inhibitors such as dichromate.

Film Inhibitors and Removers: In plant operation, corrosion is not the only important aluminum-water surface phenomenon. The formation of hydrous oxide films was found to take place on the metal service and certain materials were tried either as inhibitors for this formation or to remove the films after they had been formed. The influence of all these additives on corrosion should be known, because only those which do not cause excessive aluminum corrosion may be used. Soluble silica was one of the materials added as a film preventer. Its influence on the corrosion of 2S aluminum has previously been discussed. Since dichromate was expected to be used in the plant, it was included in most runs.

Tests in which other proposed film inhibitors and removers were used in solution are given in Table XI. Calgon was one of the inhibitors proposed and one run is given in Table XI in addition to the earlier discussion of the effect of this substance. Sodium dihydrogen pyrophosphate and Marathon lignin #365 caused no ill effects under the conditions of the test, which included dichromate and, in one case, 6 ppm SiO_2 . A waste sulfite liquor from the Kimberly-Clark Corporation (paper manufacturers) caused severe corrosion at pH 6.2 in the absence of dichromate (see Figure 29). It was not tested at higher pH or in the presence of dichromate.

A solution containing 50 ppm oxalic acid at low pH was found useful in removing hydrous ferric oxide films. This concentration of the material was used at pH 3.0, 3.5 and 4.0 without SiO_2 or dichromate. Uniform corrosion was obtained, corresponding to penetration rates of 11, 6 and 3 mils/month, respectively. Since the treatment using such solutions would continue only an hour or two at a time at rather infrequent intervals, these corrosion rates were not considered excessive. In the presence of 50 ppm oxalic acid and 2 ppm potassium dichromate, the pH below which corrosion was very rapid at 25 ft/sec was near 4.3. Runs were made at average pH values of 4.1, 4.2, 4.3. That at 4.3 showed a corrosion rate equivalent to about 0.2 mil/mo penetration, while those at 4.1 and 4.2 showed corrosion rates equivalent to about 5 mils/mo penetration.

Table XI

CORROSION OF 2S ALUMINUM IN PRESENCE OF FILM INHIBITORS AND REMOVERS
Solution Base: Simulated River Water

Run No.	ppm of Inhibitor or Remover Used	$\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$, ppm	SiO_2 ppm	pH	Flow Rate ft/sec	Temp., °C	H_2O_2 Conc. $\text{N} \times 10^5$	Corrosion, $\mu\text{g}/\text{cm}^2/\text{hr}$		Surface Pits and Roughness
								Slope of Curve, Uncl. Spec.	Ave. Rate of Metal Loss	
194	2.2 Calgon	2.2	7.4	8.1	9	95	5	-1.3(gain)	.18	None, mod. rough
193	5.2 $\text{Na}_2\text{H}_2\text{P}_2\text{O}_7$	2.0	6.2	8.0	9	95	6	-1.1(gain)	.14	None, mod. rough
188	10 "	2.0	0	7.3	22	95	1	-4 (gain)	70	None, mod. rough
143	5 WSL ^o	0	0	6.2	25	80	1	2.4	4.3	Few, mod. rough
189	10 ML ^x	2	0	7.4	22	95	1	.11	1.6	None, mild rough
156	50 $\text{H}_2\text{C}_2\text{O}_4$	0	0	3.0	25	70	2	106	106	None, mild rough
158	50 "	0	0	3.5	23	70	2	56	57	None, mod. rough
161	50 "	0	0	4.0	25	70	2	30	32	None, mod. rough
162	0	6	0	4.8	25	70	20	~2	1.8	None, mild rough
171a	50 $\text{H}_2\text{C}_2\text{O}_4$	1.7	0	4.2	25	70	17	59	55	None, mild rough
166a	50 "	2.2	0	4.3	25	70	12	2.0	17.0	None, mod. rough
168a	50 "	2.1	0	4.1	22	70	15	45	51	None, mild rough

^oWaste Sulfite Liquor from Kimberly Clark Corp.

^xMarathon Lignin No. 365

a $\text{K}_2\text{Cr}_2\text{O}_7$ used instead of $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$; mol. weights nearly the same

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RUN
143

10 x

N H O	Velocity	ft/sec
22.1.0 X 10 ⁻⁵	25	
ppm Cl ⁻ 0.8	Temp., °C	80
pH 6.2	Hours in test	407
Water	5 PPM W.S.L.	
SIM RIVER		

Figure 29

2S Aluminum Samples After Test

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Soluble Oil: Under some conditions, oils which form relatively stable emulsions have been used successfully as inhibitors for aqueous metal corrosion. It was proposed at one time to lubricate aluminum parts that would have to be moved in the plant with such an oil, "Texas soluble oil C". To investigate the influence of this material on the corrosion of 2S aluminum under conditions representative of other test runs, the following data were obtained:

TABLE XII

INFLUENCE OF SOLUBLE OIL ON CORROSION OF 2S ALUMINUM

Texas (Texaco) soluble Oil C; Solution base: Sim. River water; 9 ft/sec flow rate; 95°C

Run No.	Oil Conc., wt %	pH	H ₂ O ₂ conc., N x 10 ⁵	Corrosion μ g/cm ² /hr		Surface-pits, roughness
				Slope of curve, uncl.spec.	Ave. rate of metal loss	
178	1	4.5	1	4.0	4.4	None, mod. rough
179	7	5.5	1	2.0	2.9	None, mod. rough
180	7	6.5	1	0.28	0.5	None, mod. rough

No effects harmful to corrosion were observed except the tendency toward low pH and the difficulty in controlling pH in the presence of the oil. No rapid corrosion rate or surface attack such as pitting was noticed.

EFFECT OF OXYGEN CONTENT OF SOLUTIONS

Because of the important role that dissolved oxygen often plays in the corrosion of aluminum and other metals, the concentration of this substance in the tests run is of importance. Regular analyses were not made on all runs, but solutions of representative ones (simulated River water and distilled water) were measured. Since hydrogen peroxide interferes with the analysis used for dissolved oxygen, only peroxide-free solutions were analyzed. Conditions tested were pH 5.5, 6.5, 7.5 at 95°C and pH 6.5 at 70°C. In all cases, the oxygen concentration

seemed to be independent of pH, of the solution composition and of whether the 9 or 20 ft/sec systems were used. Values at 70°C varied between 3.8 and 4.3 ppm dissolved oxygen, and those at 95°C varied between 1.5 and 3.5 ppm, with an average of about 2.3 ppm. The number of determinations made is 27.

A few tests were run to determine the influence of the concentration of dissolved oxygen on the corrosion rate of 2S aluminum. These are given in Table XIII, with the closest comparisons available from the regular runs made. The gases were sent through small-hole bubblers into the solution in the round bottom flask which served as solution reservoir, as in Figure 2.

No effect due to concentration of dissolved oxygen could be ascertained.

TABLE XIII

OXYGEN AND NITROGEN SATURATED TESTS

Flow rate 20-25 ft/sec, temp. 80°C

Run No.	Gas Used	pH	H ₂ O ₂ Nx10 ⁵	Solution	Corrosion $\mu\text{g}/\text{cm}^2/\text{hr}$ Slope of Ave. rate cover, of metal uncl. spec.		Surface pits, x roughness
136	None	6.1	0.1	Dist. H ₂ O	0.2	0.3	None, mild rough
123	Oxygen	6.3	.1	Sim. River	.1	.66	None, mild rough
119	Nitrogen*	6.0	.1	Sim. River	.24	.80	None, mod. rough
113	None	6.6	2.	Sim. River	.96	1.64	Num., rough
135	Oxygen	6.7	0.2	Sim. River	.37	2.8	None-mild rough

*O₂ concentration between 0.05 and .10 ppm by analysis

EFFECT OF SPECIAL SURFACE PRE-TREATMENT

With the object of preparing specimens protected with corrosion resistant films, two types of treatment were used. An anodized coat was deposited on the samples in one case and a one hour dip was given them in fuming nitric acid at room temperature in the other case. The results of the corrosion test on the anodized specimens have previously been given in Table X. The coat lasted for 200-250 hours, with no corrosion

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at all apparent. After that time, the coat had worn off and corrosion seemed normal for untreated samples under those conditions (24 ppm NaNO_3 , 2.2 ppm Cl^- , 2.9 ppm Calgon, pH 6.1, 15 ft/sec flow rate 80°C , $4.7 \times 10^{-4} \text{ N H}_2\text{O}_2$).

Samples having the pre-dip in fuming nitric acid were used in Run 42 (Appendix). This coat lasted somewhat over 150 hours, preventing corrosion during that time. The samples then corroded normally in the solution used (pH 5.8, 6.6 ppm Cl^- , $0.7 \times 10^{-5} \text{ N H}_2\text{O}_2$, 95°C , 9 ft/sec). The sample weight change curve in the Appendix shows clearly the initial protection, then more rapid corrosion. The samples were not corroded as severely at the end of the run as the similar run with no pre-treatment because of the period during which no rapid corrosion occurred. After corrosion samples had an appearance somewhat worse than those from Run 38 (4 ppm Cl^-), Figure 19.

Statistical Study of Pitting of 2S Aluminum

These experiments were performed by M. W. Wainscott, with the assistance of Estelle Zoghlin, under the supervision of E. F. Story, Jr., Associate Group Leader.

It was shown that the chief danger from corrosion of aluminum at pH 6.5, and later at 7.5 in the presence of dichromate, was due to possible penetration of aluminum parts by pitting attack. In order to evaluate the danger of such attack to many pieces, corrosion tests were run, using about 50 samples, to determine the statistical probability of pitting attack and its severity.

The samples were prepared by treatment for 10 minutes in 5% NaOH at $30-40^\circ\text{C}$, rinsing thoroughly, dipping in 40% nitric acid, rinsing, drying with alcohol. In some of the early tests half of the specimens were used unetched. No difference in corrosion could be detected. In a few tests, some of the specimens were prepared in different ways for comparison as follows: 10 specimens were anodized (1/2 hr. as anode at 15 volts, $\sim 30^\circ\text{C}$ in 15% H_2SO_4 ; followed by 1/2 hr. in boiling distilled water); 10 specimens were polished on a cloth buffer, degreased in acetone; the other 30 specimens were prepared in the standard way as given above. Photographs of all specimens were taken before and after testing and while not given in this report, they are in notebooks as listed in the tables reporting the data. All weight changes were determined after stripping the oxide from the samples after test by a 15 minute treatment in a boiling solution containing 5% H_3PO_4 and 2% CrO_3 .

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The results of all tests are given in Tables A-I through A-III in the Appendix, pp 114-116. The types of test and summarized results are as follows: All tests were run in simulated River water. Run numbers are given in parentheses. In all runs except S-60 a thick white coat deposited on the samples, covering them and the sample supports. Analyses of this coat are as follows:

	Run S-10	S-11	S-12
Sulfate	0.32%	0.19%	0.31%
Aluminum	2.0	4.0	3.9
Calcium	35.5	27.9	29.2
Magnesium	1.7.	3.6	3.7
Carbonate	3.65	36.6	8.35

It is felt that the material probably was largely CaCO_3 , precipitated when the heat decomposed the bicarbonate normally present in the solution. Carbon dioxide may have been lost in the analyses.

EFFECT OF HYDROGEN PEROXIDE

From 0.25 to 10×10^{-4} N - at 70°C, pH 7.5 (S-1 to S-3)
pH 8.0 (S-7 to S-9)
- at 90°C, pH 7.5 (S-4 to S-6)
pH 8.0 (S-10 to S-12)

No consistent effect due to H_2O_2 could be found. Pitting was negligible in all cases and weight changes showed no particular effect. In the two series at pH 8, three methods of sample preparation were used as given above. Weight data on anodized samples are not given because the initial weight of the metal was unknown.

EFFECT OF pH

From 3 to 5 - at 70°C (S-13 to S-15)
- at 90°C (S-16 to S-18)
From 6.5 to 7.5 - at 70°C (S-19 to S-21)
- at 90°C (S-22 to S-24)

In the pH range 3 to 5, a rather sharp increase in metal corroded was found between 4.2 and 3.3. At 70° no pitting was observed; at 90° and pH 3.2, rather large pits formed on the sample surfaces. These are itemized in Table XIV. In the pH range 6.5 to 7.5, no pitting was observed. The metal corroded was greater at pH 7.6 than at the lower values by factors of 2 and 3, though the penetration rate still was only about 0.1 mil/mo.

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Table XIV

PITTING IN RUN S - 16
Simulated River Water, 90°C, 0.8×10^{-4} NH_2O_2 , pH 5.2, 409 Hrs.

Sample Number	Pit Depths, mm,
1	0.07
6	.06
8	.32
14	.22, .20, .31
15	.24, .16
17	.17
18	.32
19	.33
20	.10
22	.33
24	.12
25	.37, .11
26	.28, .22
29	.14, .34
30	.37, .36, .39, .39
32	.31
33	.08, .27, .29
37	.30, .27, .25
38	.22
40	.12, .33
44	.28
45	.27, .33, .30, .20
46	.34
48	.39, .38, .38
49	0.28

Samples were generally smooth. See CT 1272, pp 10-11

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EFFECT OF CALGON

From 1 to 10 ppm - at 70°C (S-25 to S-27)
and - at 90°C (S-28 to S-30)

The pH in these tests was 6.8. At 70° no pitting was observed. Starting with this series of experiments, no weight changes were measured. At 90° pitting was observed at all Calgon concentrations tried. With increasing amount of Calgon, the size of the pits increased considerably.

EFFECT OF CUPRIC ION

From 0.05 to .13 ppm ~ at 70°C (S-32, 34, 36)
and - at 90°C (S-31, 33, 35)

No pitting was observed in any of these tests, which were at pH 6.8.

EFFECT OF 5ppm CHLORIDE ION

Tests run at different times, from 7 to 28 days- at 70°C (S-39,43,47,51)
and- at 90°C (S-37,41,45,49)

The pH was 6.7 for these tests and no pitting was observed.

EFFECT OF OMITTING THE STIRRING

Tests run at different times, from 7 to 28 days- at 70°C (S-40,44,48,52)
and- at 90°C (S-38,42,46,50)

No pitting was observed in any of these tests.

EFFECT OF SODIUM DICHROMATE

From 2 to 8 ppm -at 70°C (S-53, 55, 57)
and -at 85°C (S-54, 56, 58)

No pitting was observed in these tests, which were run at pH 6.5.

TESTS OF LONG DURATION (94 DAYS)

(With and without CaSO_4 , MgSO_4 (S-59, 60)). These tests were at 85°C and pH 6.5. Wide shallow pits formed in both cases, about 0.05 mm deep. No difference was noticed between the two runs.

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EFFECT OF pH IN PRESENCE OF DICHROMATE

From 5.5 to 8.5, with 2 ppm $K_2Cr_2O_7$ - at 70°C (S-61 to 63)
and - at 85°C (S-64 to 66)
with 4 ppm $K_2Cr_2O_7$ - at 70°C (S-67, 69, 71)
and - at 85°C (S-68, 70, 72)
with 8 ppm $K_2Cr_2O_7$ - at 70°C (S-73 to 75)
and - at 85°C (S-76 to 78)

No pitting was observed in any of these runs.

EFFECT OF USING ALTERNATE COUPLED SPECIMENS OF 2S AND 72S ALUMINUM

pH from 5.5 to 7.5 - at 70°C (S-79 to 81)
and - at 85°C (S-82 to 84)

No pitting was observed in any of these runs.

Static Tests on Aluminum

All tests are reported in the Appendix in Tables and Figures. Several samples were placed on test and removed periodically for weighing, the dry weights being obtained after 15 to 30 minutes in a vacuum desiccator. After each such weighing, one sample had its oxide coat removed by 15-20 minutes treatment in the standard cleaning solution (boiling 5% H_3PO_4 , 2% CrO_3 solution). All but this one sample were then returned to further testing. Only one sample remained in test for the last period of corrosion.

Special average uncleaned sample weight gains, G' , were calculated for a typical n 'th point from the formula, $G'_n = G_{n-1} + D_{n-1,n}$, where $D_{n-1,n}$ is the average gain in weight of all the specimens on test during the period from point $n-1$ to point n . In effect this treatment assumes that the samples which were removed early in a run would have continued to corrode in the same general manner as did the ones left on test, and averages their early weighings into all the points on the curve. Points which fit smoother curves results from this treatment, allowing an easier determination of the slopes of almost horizontal curves.

From the single samples removed, the weight of the coat, C , and the actual metal lost by corrosion, L , were determined. The ratio C/L for each sample, one at each time of weighing, was then determined. If the corrosion product had the same molecular formula, and if none of this product fell from the samples during test, the ratio C/L should be the same throughout any run, for all samples. Experimentally this was found to be nearly true, only 9 out of the 47 ratios calculated being more than 15% from the average for the runs from which the data came.

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If no corrosion product were lost from the samples, the following are the expected values of C/L for various oxide compositions:

Al_2O_3	1.89
$\text{Al}_2\text{O}_3 \cdot 1/2 \text{H}_2\text{O}$	2.06
$\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$	2.22
$\text{Al}_2\text{O}_3 \cdot 3/2 \text{H}_2\text{O}$	2.39
$\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$	2.56
$\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$	2.89

All of the average values measured came within the range of values for C/L listed.

Since determined values of C/L would be low if corrosion product were lost from the sample surfaces, special averages were made using the average value of C/L for each run, assuming no corrosion product was lost.

A special average value for the actual metal lost, L' , was determined as follows:

$$\begin{aligned} C &= L + G \text{ or } C - L = G \\ (C/L - 1) L &= G \\ L &= \frac{G}{(C/L) - 1} \\ \text{or using averages, } L' &= \frac{G'}{(C/L)_{\text{ave}} - 1} \end{aligned}$$

where C, G, L, C' have been defined previously. Values of L' thus obtained gave points closely fitting curves and are more useful than values of L in the same way that G' is more useful than G.

Both G' and the negative of L' are plotted in the Appendix in Figures A-2 through A-19.

All units in Tables A-IV to A-XXI are mg/dm^2 for convenience
 $1 \text{ dm}^2 = 100 \text{ cm}^2$.

EFFECT OF SURFACE PREPARATION ON CORROSION OF 2S

Runs B-1 through B-5 were made at the same conditions ($1 \times 10^{-4} \text{ N H}_2\text{O}_2$, 1.8 - 1.9 ppm Cl^- , pH 6.6, 60°C) using the following methods of sample surface pre-treatment:

1. Ordinary as-rolled half hard 2S aluminum sheet (Run B-3)
2. Sheet pre-cleaned for 15-20 min. in 2% CrO_3 , 5% H_3PO_4 , boiling (Run B-2)

3. Sheet wet-ground with 240 grit emery paper (Run B-5)
4. Sheet cleaned in NaOH (10 minutes, 5% NaOH, $\sim 40^{\circ}\text{C}$) (Run B-4)
5. Wet ground sheet as in 3, pre-cleaned in stripping solution as in 2 (Run B-1)

All samples were degreased in alcohol or acetone before testing. The results may be seen in Tables XV, A-IV through A-VIII, and Figures A-2 through A-6. Runs B-3 and B-4 gave nearly identical corrosion curves, indicating that pre-etching in sodium hydroxide causes little change in the surface activity of the as-rolled material. Wet-grinding on 240 grit emery paper caused a greater reaction in the first 100 hours, after which the rate of reaction was roughly the same as for untreated sheet. In both cases where oxide stripping solution was used before testing, considerably slower corrosion rates were observed, presumably because of the formation of a thin impervious oxide film.

EFFECTS OF TEMPERATURE, CHLORIDE AND PEROXIDE ON 2S

Runs B-6 through B-18 were made to investigate the influence of these variables on the corrosion of 2S aluminum at pH 6.4 through 6.6. The sample surfaces were used as rolled in all cases except for run B-6, where they were wet ground. Due to the limited accuracy with which the final slopes of the curves of I^d , and thus the steady rates of metal loss, may be determined comparison of runs is often difficult. A few statements may be made: All data can be seen in Table XV.

1) In the presence of 10^{-3} N H_2O_2 , higher rates were observed at 70°C than at 95°C , both at 0 and 2 ppm Cl^- (Runs B-16 and B-8; B-15 and B-7). In the presence of 10^{-4} N H_2O_2 , the rates at 70 and 95°C were about the same at 0 Cl^- (B-14 and B-12). At 10^{-4} N H_2O_2 and 2 ppm Cl^- the rate at 95° was higher than that at 70°C (B-9 and B-6).*

2) At 70°C , both 1 and 10×10^{-4} N H_2O_2 , there was very little difference in the rates at different chloride concentration from 0 to 2 ppm (B-14, B-13, B-9; B-16 and B-15). At 95°C , both 0 and 10^{-3} N H_2O_2 , there was very little difference in the rates from chloride concentrations 0 to 2 ppm (B-11 and B-10; B-8, B-17, B-7). At 95°C and 10^{-4} N H_2O_2 , the rate for 2 ppm chloride was greater than that for 0 chloride (B-12 and B-6).*

3) At 70°C , both 0 and 2 ppm chloride, the rates were slightly greater at 10^{-3} than at 10^{-4} N H_2O_2 (B-14 and B-16, B-9 and B-15). At 95°C , 0 chloride, the rates decreased with increasing peroxide from 0 to 10^{-3} N (B-11, B-12, B-8). At 95° , 2 ppm chloride, no change was noticed from 0 to 10^{-3} N H_2O_2 , but at 10^{-4} N H_2O_2 a high rate was observed (B-10, B-6, B-7).*

Table XV

SLOPES OF CURVES OF STATIC CORROSION TESTS
pH = 6.4 to 6.6 For All Runs

Run No.	Temp. °C	Chloride ppm	H ₂ O ₂ Nx10 ⁴	Hours	Slope of G' (μg/cm ² /hr.)	Slope of L' (μg/cm ² /hr.)
B - 1	60	1.9	1.2	0-100 100-450	1.1 .05	0.8 .04
B - 2	60	1.8	1	0-100 100-450	1.05 .03	.72 .02
B - 3	60	1.8	1.0	0-100 100-450	2.4 0.17	1.4 .10
B - 4	60	1.9	1.2	0-100 100-400	2.5 0.18	1.7 .13
B - 5	60	1.9	1.5	0-100 100-450	3.7 0.13	2.5 .09
B - 6	95	2	1	0-100 100-900	1.8 0.13	1.6 .11
B - 7	95	1.7	9.2	0-100 100-1000	1.15 0.02	1.03 .02
B - 8	95	0	9.5	0-100 100-900	1.05 0.01	1.01 .01
B - 9	70	1.8	1.2	0-150 150-100	3.0 0.04	2.2 .03
B - 10	95	2.2	0	0-100 100-1100	1.45 0.02	1.34 .02
B - 11	95	0	0	0-100 100-1000	1.0 0.04	0.9 .04
B - 12	95	0	1.4	0-100 100-1000	1.05 0.03	1.09 .03
B - 13	73	1.4	1.2	0-200 200-1000	2.85 0.08	1.87 .05
B - 14	72	0	1.4	0-150 150-1000	2.6 0.04	1.6 .02
B - 15	72	2.1	13.2	0-100 100-1000	1.5 0.05	1.1 .04
B - 16	70	0	10	0-100 100-500	1.05 0.05	.92 .04
B - 17	95	1	10	0-150 150-600	1.06 0.02	1.31 .02
B - 18	70	1	10	0-150	0.45	

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It was noticed that Run B-6 resulted in conclusions which were hard to tie in with others. Since this is the only run in which the samples were wet-ground before testing, it may be that the rate of metal loss would be lower if this treatment had been omitted. The results in which this run appears above are marked with an asterisk, indicating doubtful reliability.

If the results of Run B-6 are omitted, the effects of the three variables may be seen. At 10^{-3} N H_2O_2 a negative temperature effect is observed on the corrosion of 2S aluminum and at $70^\circ C$ a slight positive peroxide effect is observed. At $95^\circ C$ and no chloride, a negative peroxide effect on corrosion is observed. No direct influence of chloride ion concentration on the corrosion is apparent in the range studied.

2S AND 72S ALUMINUM IN THE PRESENCE OF DICHROMATE

Six samples of each alloy were tested in simulated River water at $85^\circ C$, containing $\sim 2 \times 10^{-3}$ N H_2O_2 and 6.9 ppm $Na_2Cr_2O_7 \cdot 2H_2O$ (5 ppm $Cr_2O_7^{=}$) at pH 6, 7, 8 and 9. No pre-treatment was given the samples other than degreasing in acetone. The samples were removed periodically, dried in a vacuum desiccator, weighed and returned to test. The weights so obtained were averaged and are plotted in Figures A-20 and A-21.

At the end of each test, the samples were weighed and two of them were stripped of the oxide coat by 15 minutes treatment in boiling 5% H_3PO_4 , 2% CrO_3 solution. These results are given in Table XVI. The average rate of metal loss from the start of each test is given. It must be born in mind that these figures do not represent corrosion rates because the metal lost was probably not at all linear with time.

It is apparent from the values of ratio C/L in Table XVI that all of the corrosion product did not remain on the sample surfaces during the runs.

At a pH of 6 there was very little attack on 2S aluminum. The samples still had a bright metallic appearance at the end of the run, indicating the oxide coat was uniform and very thin; this was also true of the 72S samples.

At a pH of 7 the 2S samples showed adjoining grains of different degrees of brightness, looking like a typical etched sample, with many black specks scattered over the surface, apparently covering very minute pits which had stopped growing. The 72S was similar in appearance but showed fewer black specks, and practically no pits, even very minute ones, when the surface had been cleaned by use of the stripping solution.

Table XVI

STATIC CORROSION OF 2S AND 72S ALUMINUM IN DICHROMATE SOLUTION

Solution: 6.9 ppm $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$, 2×10^{-5} NH_2O_2 , 85°C

pH	Aluminum Alloy	Coat Weight, C, mg/cm^2	Metal Corroded L, mg/cm^2	C/L	Time, Hours	Average Rate of Metal Loss From Start, $\mu\text{g}/\text{cm}^2/\text{hr}$
6.0	2S	0.093	0.069	1.35	418	0.165
6.0	2S	.080	.060	1.33	418	.143
6.0	72S	.137	.100	1.37	387 1/2	.328
6.0	72S	.144	.098	1.47	387 1/2	.321
7.0	2S	.448	.547	0.82	511	1.07
7.0	2S	.497	.595	.84	511	1.16
7.0	72S	.248	.426	.58	343 1/2	1.24
7.0	72S	.250	.425	.59	343 1/2	1.23
8.0	2S	1.09	.99	1.21	418	2.37
8.0	2S	1.21	1.15	1.05	418	2.75
8.0	72S	1.34	1.03	1.30	344 1/2	3.00
8.0	72S	1.32	1.04	1.27	344 1/2	3.02
9.0	2S	2.40	.92	2.61	485	1.90
9.0	2S	2.01	.77	2.61	485	1.59
9.0	72S	1.80	.42	4.28	390 1/2	1.07
9.0	72S	1.87	.54	3.47	390 1/2	1.38

Data recorded: NB 461, pp 132-136

At a pH of 8 the oxide coat did not seem to be as uniform as at 7 or 9. The 2S samples showed a good many pits which were not very deep ($\sim .05$ mm) and some broad pits which were extremely shallow ($< .02$ mm). The 72S samples showed a network of lines which were etched out. These lines were apparently along grain boundaries, and pitting was frequent.

At a pH of 9 the oxide coat was very thick and uniform (especially uniform on the 72S) and occasionally small needle shaped crystals could be seen attached to the coat. The small pits ($< .02$ mm deep), visible when the oxide coat was stripped off, were especially uniformly distributed on the 2S samples.

Other Alloys

17ST

Very little testing was done on this alloy. Altogether four runs were made in recirculating systems at 9 ft/sec as described above for 2S aluminum. One Run-41, is reported in the Appendix. The bath contained 12 ppm chloride ion and the metal was seriously corroded. A photograph is shown in Figure 21.

Three runs were made to determine the effectiveness of sodium silicate in preventing corrosion of aluminum in alkaline phosphate-containing solutions. Alloy 17ST was used by accident, it being desired to use 2S. The results are given in Table XVII. Serious corrosion occurred with relatively low silica contents (added as sodium silicate solution). The corrosion was reduced by increasing the amount of sodium silicate present until, at 242 ppm Na_2SiO_3 , no serious corrosion occurred in the 228 hour test.

52S AND 61ST

These alloys were tested in the recirculating systems at 9 ft/sec in distilled water containing 1 ppm chloride ion. Samples were tested in the same manner as the 2S samples were. Each alloy was tested at 70°C , 2×10^{-5} N H_2O_2 and at 35°C , no H_2O_2 , both at pH 6.5. Alloy 52S was also tested at pH 7.3, 2×10^{-5} N H_2O_2 , 70°C . No pitting was noticed in any of these runs (197 through 201, see Appendix) and corrosion rates were low, the overall metal lost corresponding to less than 0.2 mil/wt. penetration in all cases.

DIE CAST ALLOYS 360 AND A 360

The samples of alloy 360 which were used contained 1.4 to 1.8% iron; those of A360 contained 0.50 to .60% iron. Both contained from

Table XVII

CORROSION OF 17ST ALUMINUM IN THE PRESENCE OF PHOSPHATE AND SILICATE
Temp. = 95°C, No Chloride Ion Added, 9 ft/sec Flow Rate

Run No.	H ₂ O ₂ , Nx10 ⁵	pH	Na ₃ PO ₄ , ppm ^x	Na ₂ SiO ₃ , ppm ^x	Time of Run, Hours	Uncleaned Rate of Wt. Change, μg/cm ² /hr	Description After Corrosion
21	6	8.7	80	62	243	127 (2 samp.) 12 (1 samp.)	Brown coat with bright corroded areas. One had no bright areas and corroded less.
22	8	9.2	84	121	297	60	Uniformly bright, roughened.
23	10	9.3	89	242	228	0.5	Uniformly dull and smooth.

^xCalculated from the concentrations in the replenishing solutions and their relative rates of flow into the system. "Egg preserver," water glass used as source of sodium silicate.

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8.6 to 9.3% Si. Analysis of other samples from the same bar stock showed:

Wt. %	Alloy 360	A360
Cu	< 0.10	< 0.10
Zn	.19	< .05
Ni	< .10	.10
Sn	< .05	< .05
Mn	.15	< .05
Mg	.54	.46

The four tests run on these alloys are given in Table XVIII. Samples were regular cast test specimens, with only the ends machined to support them. Procedures were the same as in other tests at 20 to 25 ft/sec in the recirculating systems.

TABLE XVIII

CORROSION OF DIE-CAST ALLOYS 360 AND A360

Conditions: 23-24 ft/sec, 85°C, simulated River water, 1-2x10⁻⁵N H₂O₂

Run No.	Alloy No.	pH	SiO ₂ , ppm	Na ₂ Cr ₂ O ₇ . 2 H ₂ O ppm	Time on Test hours	Corrosion, μ g/cm ² /hr Slope of curve, uncl. samples	Ave. rate of metal loss	Surface-pits and roughness
185	360	7.5	8.5	2.5	301	2.19	21.9	None, mod. roughness
186	A360	7.8	8.8	2.5	301	13.0	13.1	None, mod. roughness
202	360	6.5	0	0	370	6.4	20.6	Num. -.05-.4mm deep by .5-.2 mm diam.
203	A360	6.5	0	0	370	6.0	6.3	Mod. r.o, .05-.1 mm deep, .05-.2 mm diam.

It is seen that alloy A-360 (containing less iron) forms fewer pits and more shallow pits at pH 6.5 than alloy 360. At pH 7.5, with SiO₂ and dichromate present, a fairly heavy oxide coat formed on samples of alloy 360, while only a very light coat formed on samples of alloy A-360. Corrosion was not accompanied by pit formation under the latter conditions. The tests are given in detail in the Appendix. Samples after test at pH 6.5 are shown in Figure 30.

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RUN
202

10 X

N H O	Velocity	ft/sec
2.2×10^{-5}	23	
ppm Cl ⁻ 1.0	Temp., °C	85
pH 6.5	Hours in test	370
Water	ALLOY 360	
S.M. RIVER

RUN
203

10 X

N H O	Velocity	ft/sec
2.2×10^{-5}	23	
ppm Cl ⁻ 1.0	Temp., °C	85
pH 6.5	Hours in test	370
Water	ALLOY A-360	
S.M. RIVER		

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Figure 30

Die-Cast Alloy Samples After Test

S-49-80

ALLOY 13

Only one test was run on this alloy, a typical analysis of which shows:

Element	Si	Fe	Cu	Zn	Ni	Sn	Mn	Mg	Al
Wt. %	11.70	0.99	0.21	<0.05	<0.10	<0.05	<0.05	0.09	balance

The sample used was not analyzed and did not come from the stock analyzed as above. It was run suspended by glass in an unstirred beaker at 90-95°C, with solution replenished so that the peroxide concentration was kept at 2×10^{-5} normal. No chloride or other salts were added and the pH was 6.1. For the 490-hour test the uncleaned sample gained weight at a rate of 0.514 g/cm²/hr. After the test the surface was roughened, but showed no pits.

72S AND ALCLAD 72S OVER 3S ALUMINUM

Alclad tubes were proposed to be used as protection against penetration of the tubes by water corrosion. Specimens of 72S aluminum prepared and tests run at 20-25 ft/sec as described previously for 2S. Data are given in the Appendix. In Table XIX are shown results of all corrosion tests completed on 72S aluminum. With each run or group of runs the most nearly identical run on 2S aluminum is given for comparison. In some cases the comparison is not too good; note pH 6.0, Runs 105 and 48, and pH 5.5, Runs 116 and 57, the chloride ion concentrations do not compare closely enough to expect similar behavior. The noted differences in H₂O₂, Ca⁺⁺, Mg⁺⁺, SO₄⁼ would not be expected to cause serious differences in corrosion.

It may be seen that danger of pitting is more apparent for 72S in every case. Weight losses are not very much different except that at pH about 5 it may be said that the corrosion rate for 72S is greater than for 2S. Under most conditions investigated it is believed that 72S corrosion may be predicted with fair accuracy from knowledge of 2S corrosion.

Four tests were made at 9 and 15 ft/sec flow rate, using strip specimens sized as described for 2S. The surfaces were only degreased before test. The material used was 3S, clad on both faces with about 3 mils of 72S aluminum. On the edges 3S was exposed. According to Dr. R. B. Mears of the Aluminum Company, the corrosion properties of 3S are very similar to those of 2S. Results of the tests (in distilled water containing peroxide and chloride; at 70 and 95°C, pH 6.5 to 7.8) are given in the Appendix, Runs 70, 75, 83, 84. Evidence is that 72S corroded slightly faster than 2S. At 70°C the pitting was noticed to have penetrated just about as far as the 72S-3S interface and no farther.

Table XIX

CORROSION OF 72S ALUMINUM
 Solution: Simulated River Water
 Flow Rate: 20-25 ft/sec

Run No.	Alloy No.	pH	Temp., °C	$\frac{H_2O_2}{N \times 10^4}$	Time of Run, Hours	Corrosion, $\mu\text{g}/\text{cm}^2/\text{hr}$		Description After Corrosion
						Slope of Curve, Uncl. Spec.	Ave. Rate of Metal Loss	
104	72S	5.0	73	1.4	399	2.05	1.08	Mod. no. pits 0.05-.1 mm deep, .2 mm diam. Mod. rough surface.
124	72S	5.0	94	1.2	417	0.69	1.44	Few pits 0.08-.1 mm deep, 0.3-.6 mm diam. Rough surface.
97	72S	5.2	93	1.3	402	.91	2.5	Mod. no. pits 0.08-.1 mm deep, 0.4-.6 mm diam.
103	2S	5.0	94	0.02 ^a	423	.39	1.0	No pits, mild gen. roughness.
96	72S	5.4	94	1.3	400 1/2	0	0	Several pits, 0.02 mm deep, .15 mm diam.
92	2S	5.4	93	1.1	412	0.28	1.9	No pits, general roughness.
126	72S	5.5	80	1.3	400 1/2	.54	1.22	Few pits, 0.1-.2 mm deep, 0.6-.8 diam. Rough surface.
127	2S	5.7	80	5.2	438 1/2	1.16	2.13	No pits. Numerous oxide lumps. Gen. rough.
105	72S	6.0	92	0.2	398	3.7	6.1	Few pits 0.02 mm deep, .09 mm diam. Very dark gray coat.
148	2S	6.1	80	0.15	428	0.86	1.34	Smooth surface.
112 ^b	72S	6.9	90	0.02 ^a	401 1/2	1.3	1.80	1 or 2 pits, .04 mm deep, .45 mm diam. No oxide coat visible.
127	2S	6.9	80	.01 ^a	409	1.3	4.78	No pits. Mod. rough.
131	72S	6.6	70	1.8	401	.27	1.85	Mod. no. small pits 0.01 mm deep. Mod. rough surface.

^aNo peroxide added to solution.

^bNo calcium or magnesium sulfates added; $\text{Cl}^- = 1 \text{ ppm}$

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At 95°C the pitting tendencies are not as clear. The data do not indicate protection by the cladding, but the corrosion of either metal was not severe. The subject was not pursued further in this investigation.

Special Tests

FULL SCALE IRON SYSTEM

Early in the series of investigations of the corrosion behavior of aluminum, an all iron system was set up to run tests at conditions simulating those of actual operations. It was very similar to the stainless steel system used later by the Engineering Development Section of the Technical Division, (See Report CT 2551). Ribbed 52S aluminum tubing (1.43" inside diameter) was used, with two aluminum plugs (1.25" diameter) inside as test specimens. These plugs were 58.4 cm long and were supported by two ribs in the lower half of the outer tube (see CT 540, p. 19). The upstream sample was provided with a streamlined aluminum tip. The plugs were hollow and had 3/4" lead rods inside for weight. The solution was recirculated by an iron centrifugal pump. A 55 gallon iron drum was used for the solution reservoir and the solutions were replenished there with suitable quantities of salt solutions and distilled water. An air intake was provided on the low pressure side of the pump. The equipment is shown schematically in Figure 31 and a parts list is given in Notebook 211, page 15.

The data from these tests are given in Table AX. Where impingement attack is reported in the table, local areas of penetration of the aluminum were discovered which seemed to be associated with points of particular turbulence, such as near the front of the upstream sample and on the downstream sample just below the abutment of the upstream and downstream samples.

In general, severe corrosion of some sort was noticed whenever the pH was 8.5 or above at 70 to 75°C and when the temperature was above 80°C at pH about 7.2. At 70°C and pH ~7.3 no severe corrosion was noticed. Strong dependence of corrosion upon temperature and pH are thus indicated under the conditions tested. It will be noted that Calgon was added to all tests. Starting with Run 29, the solution carried large quantities of fine particles of iron corrosion product, presumably picked up from the iron equipment at the higher temperatures (90 to 95°C). For this reason the tests were discontinued and the equipment was re-ordered in stainless steel. Subsequent testing under more suitable conditions was done by the Engineering Development Section and the results were reported in CE 973 and CT 2550.

PLAN
Scale $\frac{1}{2}"=1'-0"$

FRONT ELEVATION
Scale: $\frac{1}{2}"=1'-0"$

Figure 31
ALL IRON CORROSION TESTING UNIT

by R.F. CARTER
12-7-42

S-49-84

Table XX

CORROSION TESTS IN FULL SCALE IRON SYSTEM
 Pressure Drop Across Test Specimens = 28.5 lbs/sq.in.
 Conditions: Flow Rate 21.6 ft/sec, Chloride = 4 ppm

Run No.	pH	Temp. °C	H ₂ O ₂ , Nx10 ⁵	Calgon, ppm	Ortho-phosphate, ppm	Downstream Water Pressure, lbs/sq.in. Gauge	Uncleaned Sample Weight Change, mg/cm ² /day		Comments
							Upstream Sample	Downstream Sample	
24 ^b	8.9	70	4	<1	?	5	-0.20	-0.25	Tan coat, impingement attack.
25 ^b	9.3 ^a	74	2	~0.4	1.5	5	- .11	- .099	Brown coat, impingement attack.
26	8.5 ^a	75	1	~5	10	5	- .22	- .060	Ditto
27	7.3	70	3	6.3	12	5	+ .03	+ .012	Still clean, except tip. No pitting.
28	7. ^a	70	3	~3	5	5	+ .05	-----	Clean, no attack.
29	7.2	94	2	~5	9	5	- .40	- .70	Thick brown coat. penetrating corrosion downstream, up to 0.3 mm deep.
30	7.3	90	2	4	5	5	- .95	-2.26	Thick brown coat. Penetrating corrosion downstream up to 0.4 mm deep.
31 ^c	7.2	90	3	5	7	30	-1.17	-1.55	Small pits all over samples.
32	7.2	81	3	6.3	2.7	10	-1.19	-----	Several areas pitted rather mildly.

^aRather bad variation, ± 1.5 units

^bSalts added to give 20 ppm Ca⁺⁺, 6.8 Mg⁺⁺, 31 ppm Na⁺, 82 ppm HCO₃⁻, 21 ppm SO₄, 62 ppm NO₃⁻

^cAlloy 17ST used. All others used 2S. Air fed in at rate of 40 cc/gal. water during runs 24-28 to simulate air liberated in plant by heating. Data are recorded in NB 217 pp 45A-49, 64-65; NB 461, pp 1-95; Log Sheets, MUC-JED 220, 6-1-45, JED to file.

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EFFECTS OF TEMPERATURE, PEROXIDE GRADIENTS AND
BOILING ON 2S ALUMINUM CORROSION

These small scale experiments were described in memo-MUC-JED-30 (N-897), March 23, 1944, to J. P. Howe from J. E. Draley.

(A) An internally heated thin walled ($\sim .030$ ") 2 S aluminum can, 1.1" diameter, 5" long, was suspended, open end up, in a distilled water solution containing 10^{-4} N H_2O_2 , 2 ppm Cl^- at pH 6, with replenishing solution flowing upward over the can at about 10 cc/min. The solution was at room temperature at the bottom of the can and boiling at the water level, before being allowed to flow off. The distance from the bottom of the can to the water level was four inches and the can was heated for more than that distance, so was considerably hotter than the water near the water level. Temperatures were measured in a thermocouple well adjacent to the inside of the can but not insulated from the $3/16$ " thick steel cylinder around the heater. It is not known how close these temperatures were to the actual temperatures of the can, but it is estimated that they are the correct order of magnitude, and the type of change with distance from the bottom is shown:

Height from bottom of can, inches	0	$\frac{1}{2}$	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4
Temperatures, deg. C	60	73	89	115	131	144	173	224	270

There was no pitting or other sign of corrosion discerned after six weeks. The oxide coating at the water line was thicker than at other parts of the surface, though still too thin to measure with the means at hand ($< .005$ mm). The oxide film was stained a golden brown at the boiling surface, and contained several cracks which seemed to extend through it; however, there was no attack of the metal beneath. This test was repeated for a shorter time with the same results.

(B) In another experiment two similar cans were held closed end to end in an unheated solution of $0.5 - 1.0 \times 10^{-4}$ N H_2O_2 at pH ~ 6 . The upper can was fitted with an arrangement for introducing 10^{-3} N H_2O_2 into the 1mm space between cans and the lower one was heated at the end to cause boiling in the region between the cans. The overall weight gain of the bottom can was approximately $3 \mu g/cm^2/hr$ and there was no indication of pitting at the hot interface after 15 days operation. There was a brown stained spot on the lower surface, opposite to the point of addition of the fresh H_2O_2 solution. The weight change was higher than that usually encountered with the solution used, but does not seem to be of a dangerous magnitude. Presumably it was actually greater than indicated by the figure, because the weight gain probably was greater at the hot surface than at other parts of the exposed surface.

As a result of the only experiments done in this group, it may be said that there seems to be no additional danger of pitting of 2S aluminum due to temperature or peroxide concentration gradient or boiling in the solutions used.

THICKNESS OF OXIDE COATS IN STEAM AND WATER SOLUTIONS

Samples of 2S aluminum were exposed to distilled water and to steam at 150 lbs/sq. in. gauge pressure. Results of these tests and the thickness of oxide coats formed in some of the static tests as reported above are reported in CT 3057, titled the Sealing of Cracks in Aluminum Surfaces.

Results showed that a two hour treatment in steam at 150 lbs/sq. in. pressure or liquid water in equilibrium with that steam should cause an expansion in surface dimensions (due to surface oxide formation) of about 4×10^{-5} cm, indicating the possibility of sealing cracks of up to twice that dimension. An additional 43 hours exposure should double this increase in surface dimension. About 100 hours in dilute peroxide-chloride solutions ($\sim 10^{-4}$ N H_2O_2 and 2 ppm Cl) at 60 to 90°C is very roughly equivalent to 2 hours in steam at 150 lbs/sq. in. With longer times of exposure at temperatures under 100°C, the continued increase in surface dimension is very slow. Wide variations in surface swelling with relatively minor changes in test conditions are indicated by the heights of the curves in Figures A-2 through A-19, this report, and in CT 3057.

COUPLED CORROSION EXPERIMENTS

Results of measurements of potentials and currents between coupled samples of dissimilar metals have been reported by R. B. Hoxeng in CT 1703 and CT 3023, and by W. W. Binger in CT 3030.

Experiments done in a recirculating system in which solutions flowed through coupled hollow specimens of stainless steel (304) and 72S and 2S aluminum at 18 ft/sec flow rate showed that there is considerable danger of galvanic attack of the aluminum, the attack being much more severe at 85°C than at 40°C. It was also shown that 2 ppm potassium dichromate added to very dilute solutions at pH 6.5 reduced the galvanic attack very much and that separating the dissimilar metal specimens by non-conducting gaskets such as Granite and neoprene decreased galvanic attack to some extent.

The same danger of pitting attack was noticed when a piece of 2S aluminum was riveted to a piece of mild steel and the couple suspended in a static system containing a solution of 1×10^{-4} N H_2O_2 , 2 ppm chloride ion at 90°C . After 12 days several pits, ranging up to 0.020 inch deep, had formed in the aluminum surface adjacent to the piece of stainless steel. The test continued for about 8 weeks longer and the $1/16$ " thick aluminum was nearly penetrated by pits in some places near the steel junction.

Ordinary mild steel samples were coupled to samples of aluminum and tests run in recirculating systems. Specimens of iron and aluminum (all specimens about $3/8$ " x 3 " x $1/16$ ") were used in the same systems as blanks. The two tests were at the following conditions:

- (a) 11 ft/sec flow rate, pH 8.8, 90°C , 5.6×10^{-5} N H_2O_2 , 3.8×10^{-4} M Na_3PO_4 ;
- (b) 6 ft/sec flow rate, pH 7.3, 90°C , 7.5×10^{-5} N H_2O_2 , 4.2×10^{-4} M Na_2HPO_4 .

The phosphates were present as possible inhibitors of galvanic attack. In Case (a) the aluminum dissolved rapidly due to the high pH, and without pitting. In both cases the iron-coupled aluminum sample corroded slightly less than the uncoupled sample. In Case (b) a uniform smooth dark film formed over the aluminum and after this had happened, the weight change was slightly positive. Possibly phosphate is an inhibitor to the galvanic attack of aluminum by iron under these conditions, although the mechanism is not clearly understood. Attack in the absence of phosphate had not been demonstrated. These tests were run early in the testing program and there is some question as to the purity of the aluminum used. The data are given in the monthly report for December 1942, CT-393, Section II, Chemistry Group C-II B.

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RESULTS OF INVESTIGATION

Discussion

The Measurement of "Corrosion Rates" in Recirculating Systems

When weight measurements are made on samples in the process of measuring corrosion, the only weights which are completely reliable are those of the metal specimens containing no oxide or other film. This leads to the conclusion that probably the most sound method of determining corrosion rates is to run several tests under the same conditions, strip the film from the samples at the end of each of the tests, which are of different duration. The slope of the final linear part of the curve (if it became linear) of the metal lost (average of a few samples) vs time on test would give the corrosion rate for the period measured. Corrosion would be expected to continue at this rate for longer periods of time, due to the linearity of the curve. A few additional tests would give some indication as to how long this linear rate would continue for representative test conditions.

The only objection to this type of corrosion data is that either different samples or different solutions would have to be used for the tests of different duration at conditions which were supposed to be identical.

In the present investigation it early became evident that the number of conditions under which 2S aluminum should be tested would be very great. To have made several tests at each set of conditions would necessarily have reduced by a considerable factor the number of different sets of conditions tested with the manpower and equipment available. The value of thus using more time per corrosion rate determination is problematical at any rate, because individual laboratory-measured corrosion rates of relatively great accuracy are not necessarily more valuable than the less accurate ones described below. There are several factors such as sample size and shape, type of water flow, surface to volume ratio, aeration, solution composition, etc., that make reliable laboratory duplication of actual conditions nearly impossible. For this reason it is felt that a comparison of rates at slightly different conditions, to determine the specific effects of the variables involved, is in general the most valuable laboratory study to be made in the case of the present investigation. If the corrosion rates measured are adequate for the above purpose, then it might be that no further accuracy need be asked of them. It is thus advisable to balance the accuracy of the corrosion rates determined against the amount of time and manpower consumed in the determination, for any method used.

The method adopted in running tests in the recirculating systems was to make only one determination at each set of conditions. Uncleaned samples were removed periodically during each test and weighed as described above in the course pursued in study. The slopes of the curves thus obtained were used as the "corrosion rate." This slope is identical with that obtained by actually stripping the oxide from the samples at each weighing as in the preceding paragraph only if drying the coat does

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not change subsequent corrosion and if the weight of the coat on the samples is the same during the part of the run where the slope of the weight change curve is used.

Some early tests on 2S aluminum in static systems indicated that drying the coat did not materially alter subsequent corrosion, and the fact that the linearity of the weight change curves was not noticeably influenced by the length of time between dryings for weighing in the case of the runs in recirculating systems is some evidence that this procedure is not unsound. No further proof of the point is available.

To determine if the weight of the coat was constant during the period when corrosion rates were often determined, from about 150 to 400 hours, four runs were made at 9 ft/sec flow rate, pH about 6.5 and 7.8, simulated River water and distilled water containing dilute peroxide and chloride. The conditions, chosen to be as nearly representative as possible, are given in Figures 32 through 35, and the data are presented in these figures and in Table XXI. Six samples were used in each test. These were periodically removed, one at a time, and the coat removed. Other procedures were as given for regular runs in the recirculating systems.

Within normal variation expected from sample to sample, the coat weights remained constant during the period of measurement for Runs 114, 204 and 206, and the slopes of data from the uncleaned samples were the same as those from cleaned samples. During Run 205 the pH rose, out of control, for a several hour period. The coat weight, relatively constant before that time, increased sharply, then seemed to be dropping toward the value noticed in the first three measurements.

It is therefore believed that under the conditions tested in the three successful runs the slope of the average uncleaned sample weight change curve is an accurate measure of the corrosion rate of the metal. Furthermore, in a great majority of the tests in the recirculating systems, the same conclusion is believed to be valid. Irregular variations around an average value of coat weight during a run should not, in the average case, change the slope of the uncleaned sample weight change from that of the cleaned samples (although determination of the slope might be made more difficult). A gradual increase in the amount of coat would cause a difference between the two slopes. However, adequately accurate estimation of increasing coat thickness was possible by visual observation in many cases (except where the coat was heavy) and the phenomenon was not observed to occur. It does not seem particularly likely that a coat would have built up early in the run, then gradually have diminished as the run progressed. Visual evidence records no such cases. In those cases where this did occur, longer runs would have shown a tendency toward lower corrosion rates. Those tests which were run for periods longer than the usual standard 400 hours (several lasted from 650 to 800 hours) showed no such tendency.

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Conditions:
 pH 6.6
 Flow rate 9 ft/sec
 Temp. 94°C
 Ca⁺⁺ 24 ppm

H₂O₂ 1.2 x 10⁻⁴ N
 SO₄⁼ 143 ppm
 Cl⁻ 1.2 ppm
 Mg⁺⁺ 5.1 ppm

△ Ave. of all samples (uncleaned)
 ⊙ For individual samples (uncleaned)
 x For indiv. samples (cleaned)

Figure 32

UNCLEANED AND CLEANED SAMPLE WEIGHT CHANGE CURVES FOR
 RECIRCULATING SYSTEMS - RUN 114

16-64-8

Conditions:

pH 7.8

Flow rate 9 ft/sec

Temp. 80°C

Ca⁺⁺ 20 ppm

Mg⁺⁺ 6.4 ppm

H₂O₂ 2 x 10⁻⁵ N

Na₂Cr₂O₇·2H₂O 2 ppm

SiO₂ 10 ppm

SO₄⁼ 85 ppm

Cl⁻ 1 ppm

Δ Ave. of all samples (uncleaned)

○ For indiv. samples (uncleaned)

x For indiv. samples (cleaned)

Figure 33

UNCLEANED AND CLEANED SAMPLE WEIGHT CHANGE CURVES FOR

RECIRCULATING SYSTEMS - RUN 204

Conditions:

pH 6.5

Flow rate 9 ft/sec

Temp. 95°C

H₂O₂ 2 x 10⁻⁵ N

Cl⁻ 1 ppm

Dist. H₂O

△ Ave. of all samples (uncleaned)

○ For indiv. samples (uncleaned)

x For indiv. samples (cleaned)

Figure 34

UNCLEANED AND CLEANED SAMPLE WEIGHT CHANGE CURVES FOR
RECIRCULATING SYSTEMS - RUN 205

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Conditions:

pH 6.5

Flow rate 9 ft/sec

Temp. 95°C

Ca⁺⁺ 20 ppm

H₂O₂ 2 x 10⁻⁵ N

Mg⁺⁺ 6.4 ppm

SO₄⁼ 85 ppm

△ Ave. of all samples (uncleaned)

○ For indiv. samples (uncleaned)

x For indiv. samples (cleaned)

Figure 35

UNCLEANED AND CLEANED SAMPLE WEIGHT CHANGE CURVES FOR

RECIRCULATING SYSTEMS - RUN 206

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Table XXI

SAMPLE COAT WEIGHTS DURING CORROSION TESTS IN RECIRCULATING SYSTEMS
Test Conditions Given In Figures 32 Through 35

Run No. Time Hours (mins. 204-206)	Weight of Coat Found On Each Sample, mg/cm ²				Time, Hours (for run 114)
	204 (See fig. 33)	205 (See fig. 34)	206 (See fig. 35)	114 (See fig. 32)	
161	0.25	0.19	0.23	0.47	176
209	.25	.16	.33	.45	228
257	.28	.19	.31	.56	276
305	.31	.42*	.29	.46	320
343	.28	.37	.17	.47	359
391	.33	.32	.27	.49	407

*Before this point the pH rose, out of control. Subsequent coat weights seem to be approaching those at 257 hours and before.

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Consequently it is believed that in most of the runs made in recirculating systems the slope of the linear part of the uncleaned sample weight change curve offers a reasonably satisfactory measure of the corrosion rate. There are several cases where this method is not satisfactory. It has been pointed out earlier in this report that quite low "corrosion rates" are not considered reliable. This is probably because the corrosion rate is so small that variations in coat weight which normally are not very important cause large changes in the slope of the best line drawn through the determined points. Such cases of low corrosion rate are sometimes accompanied by an increase in uncleaned sample weights with time and when this occurs no regularly determined "corrosion rate" can be reported as significant.

To summarize, the following offers a clear, if not entirely proved picture of the corrosion process. Where serious pitting is not too large a contributor to wt change:

- 1) There is a given rate of loss of the oxide, which forms as the corrosion product, peculiar to a particular solution under a given set of external conditions. This is the corrosion rate which is desirable to measure as long as a constant weight of oxide remains on the sample surface during corrosion. There is some experimental evidence that the latter is true.
- 2) The rate of formation of the oxide is rapid initially, due to the free access of the solution to the unprotected metal. This sometimes causes an initial weight gain, sometimes a relatively rapid loss. It is presumed that the solution constituents control the stability of the originally formed oxide at a given set of external conditions to a more noticeable and perhaps to a less reproducible extent than later in the corrosion process.
- 3) As corrosion proceeds, the rate of loss of the oxide becomes constant as its form is stabilized, and the protective oxide coat builds up until it limits access of the solution to the surface to the amount causing attack of the metal at the same rate as the oxide is lost to the solution. From this point on the weight change curve is linear and its slope is the true corrosion rate of the metal. It is not necessary to decide whether the reaction proceeds by an electrochemical mechanism or not for this discussion.

From the data available, one other kind of corrosion measurement can be reported. At the end of each run, usually one sample was cleaned of all coat and weighed. The average rate of metal loss from the start of the test is thus available for that sample. This average rate is accurate but cannot be considered a good "corrosion rate" if by that term is meant the rate at which corrosion may be expected to proceed at any time after the initial period of adjustment. It is apparent in most cases, as shown in Figures 32-35 for example, that the straight line from the origin to the last cleaned sample point does not have the same slope as that drawn through the several intermediate points.

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corrosion was quite slow, these average rates of metal loss were found valuable to supplement the sometimes useless "corrosion rates."

It is quite clear that the adopted method of determining "corrosion rates" for recirculating systems is not necessarily applicable to other conditions. In the static tests, for example, the slopes of the uncleaned sample weight change curves were completely different from the slopes of the cleaned sample weight change curves.

Strength of the Protective Oxide Film:

It was frequently noticed in tests in the 9 and 15 ft/sec recirculating systems that the edges of the samples were most susceptible to pitting attack. At these edges, the samples were usually in contact with the glass sample tube and vibration of the samples within this tube often occurred. Since contact with glass sample holders (hooks) did not seem to result in the same amount of pitting and motion of the samples relative to these hooks was not noticed as much as that relative to the sample tubes, it is believed that the vibration was responsible for the extra attack noted at the edges. The attack did not occur as often on the edges at the ends of the samples where there was no contact with other pieces. It is believed that the vibration must have weakened the protective oxide film on the side edges of the samples.

Similar attack was noticed in the 20 to 25 ft/sec recirculating systems in those cases where the glass sample spacers held the samples rather loosely and vibration occurred. It would seem therefore, that in using aluminum for constructing any plant where corrosion in dilute solutions is a consideration, vibration or motion of any aluminum parts while in contact with other parts should be avoided.

The Possibility of Other Protective Coats:

When the statistical tests were run to determine the probability of pitting attack it was found that no observable pitting occurred, even at some conditions which previous tests in recirculating systems had indicated would cause serious pitting. Reduced flow rates from those in the recirculating systems offers one possible explanation, but it is not believed to explain completely the reduction in pitting. Particularly when the solution contained 5 ppm chloride ion, some pitting was expected to occur. Even in static tests, rare pitting had been observed with as little as 2 ppm chloride ion present.

Two other explanations seem possible. In the statistical tests about fifty samples were electrically connected by supporting the samples on heavy aluminum wire, crimped to ensure tight fit. R. B. Mears of the Aluminum Company has collected data in the past which show that the formation of a pit on a sample is inhibited by the existence of a previously started pit. With such a large effective single sample area in the available quantity of solution and constituents, it might be that

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extremely small pits partially inhibit the formation of larger ones. Such an explanation does not have any real evidence to back it up, however.

Perhaps the most likely explanation of the lack of pitting in these tests is connected with the observed formation of heavy deposits of calcium-containing coats, believed to be largely calcium carbonate, as previously remarked. It is possible, and perhaps likely, that such deposits would offer protection of the samples from corrosion including the pitting type of attack. No such heavy coats were deposited in the recirculating system, probably due to the higher solution velocity, although some instances of the deposition of smaller quantities of coats with similar appearances were observed.

Mechanisms of the Corrosion Reactions:

In observing the samples after removal from the various tests, a distinct difference in appearance was noted between those in which the pH was below about 7 (the figure was never accurately determined) and those in which the pH was above about 7. When corrosion was apparent in the slightly acid solutions, it was usually characterized by pits which were filled with aluminum oxide and by formations of the oxide on the sample surfaces. After talking to Dr. Mears of the Aluminum Company, we had come to the opinion that such corrosion was largely electrochemical in nature. The pits seemed to have been caused by a reaction in which they were anodic to the rest of the aluminum surface and local electric cells were set up. The products of such reactions are usually nearly completely aluminum oxide and hydrogen according to Dr. Mears. Experimental evidence for the electrochemical theory and the oxide corrosion product has been collected at the Alcoa Research Laboratory, though most of the work done has been at conditions somewhat different than those in this investigation.

In the slightly alkaline solutions with no dichromate present, the samples frequently had a clean shiny appearance and very little oxide adhered to the surface. Tiny indentations with shiny surfaces covered the sample surfaces in the typical case, and when larger cavities were observed, they never contained bulk oxide. These cavities, only infrequently observed, were associated with points of unusually severe turbulence. They usually were of a different shape than the pits observed in slightly acid solutions, their formation seeming to depend upon external conditions, such as the geometry of the testing systems. The solubility of aluminum oxide is greater in slightly alkaline solutions than in slightly acid solutions, the pH of minimum solubility being near 6.5.

It is therefore believed that the mechanism of the corrosion of aluminum in slightly acid dilute aqueous solutions is different than that in similar slightly alkaline solutions. It is believed that most phenomena in the slightly acid solutions can be explained, using the theory that corrosion is largely electrochemical, as previously described (p. 10).

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It is believed that the corrosion phenomena in the slightly alkaline solutions can be explained adequately on a straight chemical basis in which the following equations represent the reactions:

It should be pointed out that both the electrochemical and straight chemical reactions involve the transfer of electrons; in the former case the distance between sites at which the oxidation and the reduction take place is greater than one atomic distance in the aluminum lattice, and in the latter case both oxidation and reduction occur at the same place.

Where protection from corrosion is attained in slightly acid solutions, the formation of a tightly adherent oxide film seems responsible. Any influence which tends to break the continuity of this film should result in increased corrosion. Mechanical action seems to have this result, as previously pointed out.

The effect of pH on corrosion has been discussed. The solubility of the protective oxide film in fairly strong acid and its increasing solubility with increasing pH above 7 probably explains the influence of pH on the corrosion of aluminum.

The effect of temperature on the corrosion rate in slightly acid solutions (p.29) is not too well understood. At 9 ft/sec flow rate a positive dependence of corrosion rate in temperature seems to have been found, while at higher flow rates no such dependence was evident. The probability of the formation of oxide of different compositions and stabilities (and thus protective powers) at different temperatures has been noted (p.11). It is possible that higher temperature causes more rapid corrosion by reducing hydrogen overvoltage; but that the oxide formed at 95°C is more resistant to abrasion than that formed at 70°C. A dependence of corrosion rate on temperature would be possible then at 9 ft/sec flow rate, while at higher flow rates the lower temperature oxide would be swept from the sample surface just as rapidly as the mechanically stronger oxide formed at 95°C. This theory will also be useful in the next paragraph, where the effect of flow rate will be discussed. At pH above 7, the lack of a good insoluble protective film allows for faster reaction between the metal and the solution at the higher temperature (p. 29).

The effect of flow rate in fairly strong acid and in weakly alkaline solutions is easily understood (p.29). No adequate protective film prevents more rapid reaction with greater eroding and film removing influences. In the slightly acid pH range, the supposition that films of different mechanical strength form at 70 and 95°C, as proposed in the preceding paragraph, is useful. At 70°C, the relatively weak film allows the normal

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corrosive action of higher flow rates. At 95°C, the relatively strong film resists the effect of the higher flow rate and no increase in corrosion rate was observed.

The effect of chloride ion in weakly acid solutions was investigated only at 9 ft/sec flow rate (p. 35). The corrosive effect of higher chloride concentrations was much more noticeable at 95°C than at 70°C. Apparently the type of oxide which it is proposed formed at 95°C is not more resistant to the specific attack of the chloride ion than that formed at 70°C, perhaps even considerably less resistant. In view of the strong complex ions that aluminum forms with chlorides and halides in general, it is suspected that chloride ions are held tightly to the surface of the oxides formed. This probably would have occurred since the beginning of the corrosion reaction, and contaminated oxide films would form and result in a considerably less insulating film, both electrically and mechanically. It is quite possible that the charge distribution in the lattice of the 95° oxide film is such that it is more susceptible to "adsorbed" chloride ions than the oxide formed at 70°C.

The effect of hydrogen peroxide is slight and the effects observed were not definite enough to warrant conjecture as to its role here.

The effect of Calgon probably was to contaminate the protective film with aluminum phosphate, some forms of which are only very slightly soluble. The resultant film was certainly considerably less resistant to corrosion than the normal aluminum oxide film. The way in which the presence of Calgon influences the effects of other variables is compatible with this view.

The effect of dichromate ion under slightly alkaline conditions probably was to cause the formation of a stable protective film, probably containing at least some chromium, where adequately protective films did not form in its absence. Complete absence of local attack and of rapid corrosion in general resulted from the addition of dichromate. Since corrosion rates are kept low by the presence of dichromate in the testing solution, the criterion of safety as regards penetration of aluminum parts in such solutions should be the absence of local attack. Dichromate seems to prevent such attack.

The effect of dissolved silica seems to have been to increase the rate of dissolution of aluminum oxide films in the slightly alkaline range. No local attack was observed due to its presence but local attack of the impingement type probably would be enhanced. Dichromate ion apparently offered adequate protection from the oxide dissolving action of the silica.

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Conclusions

An extensive laboratory investigation has been made to determine the corrosion behavior of 2S aluminum under conditions designed to simulate those at the H.E.W. Hydrogen peroxide was added to the solutions in an attempt to simulate the effect of plant operating condition on corrosion.

The effects of several variables which were of interest to H.E.W. operation have been investigated and a theory to explain the phenomena observed has been proposed, which involves the formation of a mechanically stronger oxide film at 95°C than at 70°C. No direct evidence is given to support this theory.

pH (measured at 30°C)

2S aluminum corrosion rates were minimum within the general pH range from 5.5 to about 7.5, with the least danger due to corrosion at pH near 6.5, in the absence of corrosion inhibitors. Lowering the pH caused increased pitting. When 2 ppm $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ was present at pH between 7 and 8, only very mild attack occurred, with danger of penetration of aluminum parts very slight, at temperatures from 70 to 95°C. In the absence of dichromate, areas of local attack were found in this pH range, believed due to local turbulence and other external factors.

The major part of the work reported was done at pH near 6.5, in solutions containing dilute H_2O_2 , chloride, usually calcium and magnesium sulfate, all at the concentrations expected at H.E.W. The temperature and solution flow rate were varied near values expected at H.E.W. The effects of the variables to be discussed in the next several paragraphs were determined for 2S aluminum or near pH 6.5.

Results on 2S at pH near 6.5: Temperature Flow Rate, Chloride, Hydrogen Peroxide, Calgon, Calcium and Magnesium Sulfates, Pre-formed Oxide Films, Sodium Nitrate and Nitrite, Waste Sulfite, Liquor, Surface Preparation

At the lower flow rates (9 ft/sec) increasing the temperature caused more rapid corrosion, while at higher flow rates (20-25 ft/sec) no effect of temperature on corrosion rate was observed.

At 70°, and less so at 80°C, increasing the flow rate from 9 to 25 ft/sec caused increases in the corrosion noted. At 95°C, no such effect was believed to have been shown (evidence scanty).

Chloride ion in solution above 2 ppm increased the amount of corrosion observed to occur in those solutions at 9 ft/sec flow rate. The effect was much more noticeable at 95°C than at 70°C.

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Hydrogen peroxide ($\sim 10^{-5}$ N) caused a slight increase in corrosion over the case in which no peroxide was added at 80°C , 25 ft/sec flow rate. At 80 and 95°C , slight general increases in corrosion occurred with increasing peroxide concentrations (up to 10^{-3} N) while at 70° , no effect was discovered at flow rates from 9 to 25 ft/sec. Conflicting effects, all minor, were obtained in non-flowing systems.

Calgon caused general increase in corrosion by its presence in solution from 3 to 11 ppm.

No consistent influence on corrosion due to the addition of calcium and magnesium sulfates (20 ppm Ca^{++} , 6 ppm Mg^{++}) to distilled water could be found.

Preformed oxide films offered temporary protection from corrosion (up to about 250 hours at 15 ft/sec flow rate, 80°C). Anodization and fuming nitric acid were used.

Sodium nitrate, a possible oxidizing inhibitor, showed only slight corrosion inhibition. Sodium nitrate similarly offered only very slight protection at concentrations up to 14 ppm.

Kimberly-Clark waste sulfite liquor, present at 5 ppm, caused a considerable increase in corrosion over that observed in its absence, tested at 25 ft/sec flow rate.

Texas soluble oil C showed no noticeable influence on 2S aluminum corrosion, when present up to 7%.

Different types of sample surface preparation resulted in somewhat different rates of attack in non-flowing systems. The phosphoric-chromic acid stripping solution used reduced subsequent corrosion.

Results at pH 7 to 8:

Dichromate ion reduced attack to a satisfactory degree, as previously noted. In its absence, strong positive dependence of corrosion on temperature, pH and flow rate were observed.

Film inhibitors such as Marathon lignin No. 365, sodium acid pyrophosphate had only minor effects in the presence of 2 ppm $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$.

Other Results on 2S Aluminum:

50 ppm oxalic acid at pH's 3 to 4 caused high penetration rates (3 to 11 mils/mo) of aluminum at 70°C and 25 ft/sec flow rate, no local attack being apparent. Dichromate ion did not prevent this attack.

No effect due to changing solution oxygen contents from 0.1 to saturation at 80°C could be detected at pH 6.2 and 6.7 simulated River water, 20-25 ft/sec flow rate, no added peroxide.

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There was found no additional danger of pitting due to temperature or peroxide concentration gradient or boiling under the conditions tested (essentially nonflowing; $10^{-4}\text{NH}_2\text{O}_2$, 2 ppm Cl^- , pH ~6).

Statistical tests to determine the probability of pitting attack failed because pitting did not occur, although it was believed that the solutions used would cause some pitting attack.

Coupling 2S aluminum to 304 stainless steel caused serious pitting attack of the aluminum at pH 6.5 as well as at 7.5, in the absence of dichromate. The addition of dichromate very much reduced the attack noted in its absence.

The Corrosion of Other Aluminum Alloys:

Sodium silicate (242 ppm SiO_2) was observed to prevent the rapid corrosion of alloy 17ST which was found at lower silica concentration in solutions containing $10^{-4}\text{NH}_2\text{O}_2$, ~80 ppm Na_3PO_4 at pH about 9, 95°C, 9 ft/sec flow rate.

The corrosion of alloys 52S and 61ST was very similar to that of 2S at 9 ft/sec flow rate, 1 ppm chloride, 70°C, $2 \times 10^{-5}\text{NH}_2\text{O}_2$ and at 35°C, no H_2O_2 , both at pH 6.5. Alloy 52S was also tested at pH 7.3, $2 \times 10^{-5}\text{NH}_2\text{O}_2$, 70°. No pitting was observed and penetration was 0.2 mil/mo. or less in all cases.

Die cast alloys 360 and A360 were observed to pit at pH 6.5, 23 ft/sec flow rate, 85°C, simulated River water, $1-2 \times 10^{-5}\text{NH}_2\text{O}_2$. Alloy A360, containing less iron, pitted less severely than alloy 360. In similar solutions at pH 7.5 to 7.8, no pitting was observed. Comparison of the corrosion of the two alloys was difficult because of the difference in oxide coats formed. Penetration rates were of the order of 2 mils/mo or less.

Alloy 7Z was tested under several conditions at 20 to 25 ft/sec flow rate. Danger of pitting of 7Z was more apparent for 7Z than for 2S under all conditions tested. Weight changes of the two alloys under similar conditions were nearly the same. Experiments on alclad indicated that the protection of the 3S (no 2S available at the time) by 7Z was dubious. Although the corrosion properties of 3S are reputed to be almost identical with those of 2S, the minor nature of the galvanic attack is such that the tests using 3S did not provide data which were valuable in this regard.

Application to Plant Operation

From the corrosion tests run in this investigation, it is considered that 2S aluminum corrosion is slight enough so that the use of the material should be safe in Columbia River water at:

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- (a) pH 6 to 7, temperatures 70° to 95°C (and probably all lower temperatures), zero to 10⁻⁴ normal hydrogen peroxide, zero to 25 ft/sec flow rate, zero to 2 ppm chloride ion, with no other materials added to the water;
- (b) pH 7 to 8, other conditions identical to (a) as long as 2 ppm Na₂Cr₂O₇·2H₂O is present as a corrosion inhibitor.

The most danger of corrosion in cases (a) and (b) is believed due to local attack of the metal, causing penetration of the aluminum cans or tubes. Uniform penetration probably would usually be less than 1 and never over 2 mils/mo.

It must be emphasized that this does not necessarily predict that 2S aluminum may be used according to plans at H.E.W. at the above conditions without any serious corrosion. No good simulation has been made of the effects of radiation and external factors such as the geometry of construction, presence of other construction materials, metal surface to solution volume ratio, etc. Tests nearer actual conditions should and have been made elsewhere.

A great deal of the value of this investigation has already been realized. 2S aluminum was chosen as slug coating and tubing material. Originally pH 6.5 was chosen for operation, but this figure was changed because of additional problems from the formation of hydrous oxide films in the corrosion testing units at Hanford.

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APPENDIX

The work of collecting the data used in this report was done by the following people:

Recirculating Systems: J. E. Draley, Ralph W. Berger
E. F. Story, Jr., John W. Arendt

Statistical Testing: M. M. Wainscott

Static Tests: G. C. English

Special Tests: J. E. Draley, E. F. Story
M. M. David, E. L. Henry,
G. C. English, M. M. Wainscott

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A list of previous Project publications reporting results of work covered in this report follows:

Monthly Reports:

CT-393, Section II-Dec. 15, 1942
CT-423, Jan., 15, 1943
CT-483, Feb. 20, 1943
CT-540, March 27, 1943
CT-610, April 24, 1943
CT-687, May 29, 1943
CT-752, June 26, 1943
CT-817, July 24, 1943
CT-892, Aug. 28, 1943
CT-955, Oct. 2, 1943
CT-1108, Nov. 30, 1943
CT-1182, Jan. 1, 1944
CT-1272, Feb. 1, 1944
CT-2668, Jan. 15, 1943

Monthly Status Reports:

MUC-ABG-53, Feb. 29, 1944
MUC-ABG-68, March 31, 1944
MUC-ABG-134, April 30, 1944
MUC-ABG-149, May 31, 1944
MUC-ABG-193, June 30, 1944
MUC-ABG-234, July 31, 1944
MUC-EWB-266, Aug. 31, 1944
MUC-EWB-284, Sept. 30, 1944
MUC-EWB-310, Oct. 31, 1944
MUC-EWB-333, Nov. 30, 1944

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Memos:

- MUC-JED-11, J. E. Draley to H. W. Bellas, 12/24/43,
Low pH Corrosion of Aluminum.
- MUC-JED-30, (N-897 (CT-C)), J. E. Draley to J. P. Howe, 3/23/44,
Effects of Temperature and Peroxide Concentration
Gradients on Corrosion of 2S Aluminum.
- MUC-EFS-6, E. F. Story to J. B. Miles, 12/9/43,
Low pH Corrosion of Aluminum.
- MUC-JPH-52, J. P. Howe, 6/5/43,
Summary of Meeting on Aluminum Corrosion.
- MUC-JPH-81, 7/24/43 } N-54 (CT-C), J. P. Howe and J. E. Draley
MUC-JPH-121, 9/21/43 }
Summaries of Corrosion Data Obtained.
- MUC-JPH-136, J. P. Howe to S. K. Allison, 10/13/43,
Corrosion of 72S Aluminum.
- MUC-JPH-154, (N-209 (CT-C)), J. P. Howe to C. M. Cooper, 11/2/44
Effect of pH on Corrosion of Aluminum.
- MUC-JPH-174, (N-419 (CT-C)), J. P. Howe to H. W. Bellas, 1/6/44
Hydrogen Peroxide As An Aluminum Corrosion Inhibitor.
- MUC-JPH-207, (N-905 (CT-C)), J. P. Howe to M. C. Whitaker, 3/30/44,
Corrosion of 72S Aluminum.
- MUC-JPH-220, (N-994 (CT-C)), J. P. Howe to H. Worthington, 4/20/44,
Corrosion of 72S Aluminum and 72S/2S Aluminum Couples.
- MUC-HWB and JPH-26, (N-307 (CT-C)), H. W. Bellas and J. P. Howe
to C. M. Cooper, 11/25/43,
Visit to Hanford Eng. Works, CMK.
- MUC-HWB and JPH-29, (N-401 (CT-C)), H. W. Bellas and J. P. Howe
to J. B. Miles, 12/29/43,
The Effect of pH on the Corrosion of Aluminum and Iron.

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Different oxide films at different temperatures in water - information from R. B. Mears, Aluminum Company.
3. J. D. Edwards, Proc. Am. Soc. Test-Mat., 1940 (Preprint), titled
Thickness of Anodic Coatings on Aluminum.
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Sample calibration of recirculating system flow rate manometer.

(A) A 9 ft/sec System:

I. D. of sample tube = 10.0 mm

Cross-sectional area of average sample = 0.14 cm x 0.90 cm = 0.126 cm²Cross-sectional area of liquid = $\frac{\pi (1.00)^2}{4} - 0.126 = 0.659 \text{ cm}^2$

To convert liters/min throughput to ft/sec linear velocity across samples,

$$\text{multiply by } \frac{1000}{0.659 \times 60 \times 30.45} = 0.830$$

Manometer reading cm	Time/18 liters seconds	Delivery liters/min	Velocity ft/sec
16	98	11.0	9.1
22	84	12.9	10.7
31	72	15.0	12.5
36	63	17.1	14.2
43	56	19.3	16.0
53	50	21.6	17.9
59	47	23.0	19.1

(B) A 20 ft/sec System:

I. D. of sample tube = 10.0 mm

Diameter of sample = 1/4 x 2.54 = 0.635 cm

Cross-sectional area of liquid = $\frac{\pi (1.00)^2}{4} - \frac{\pi (0.635)^2}{4} = 0.468 \text{ cm}^2$

To convert liters/min throughput to ft/sec linear velocity across samples,

$$\text{multiply by } \frac{1000}{0.468 \times 60 \times 30.45} = 1.17$$

Manometer reading cm	Time/18 liters seconds	Delivery liters/min	Velocity ft/sec
33	34	31.8	37.2
15	45	24.0	28.1
2.5	115	9.4	11.0

Preparation of simulated River water solutions:

(A) Stock solutions prepared as follows: (Use Bakers CP chemicals)

Ca⁺⁺: Add 18 gm CaCO₃ and 90 ml 4N sulfuric acid to 18 liters distilled water. Stir vigorously. 2250 ml of this solution in 45 liters gives 20 ppm Ca⁺⁺ and 48 ppm SO₄ =

Mg⁺⁺: Dissolve 81.2 gm MgSO₄·7H₂O in 1 liter of distilled water. 35 ml of this solution in 45 liters gives 6 ppm Mg⁺⁺ and 25 ppm SO₄ =

Cl⁻: Dissolve 3.3 gm NaCl in 1 liter of distilled water 22.5 ml of this solution in 45 liters gives 1 ppm Cl⁻

H₂O₂: 1 ml Superoxol in 45 liters gives 1 x 10⁻⁴ N H₂O₂

SiO₂: Dissolve 43 gm Na₂SiO₃·9H₂O in 1 liter of distilled water. 50 ml of this solution in 45 liters gives 10 ppm SiO₂.

Use 0.2N NaOH and 0.2N H₂SO₄ to adjust the pH of the solutions.

(B) A solution is prepared for use as follows, using a mixing bottle calibrated to 45 liters:

Add 2250 ml Ca⁺⁺ stock solution, 35 ml Mg⁺⁺ stock solution, 22.5 ml Cl⁻ stock solution, a pipetted amount of Superoxol, and fill to the mark with distilled water. Stir the solution to insure adequate mixing. It was found to take more than the calculated amount of Superoxol (rated 30% H₂O₂) to give desired concentrations of H₂O₂. Some of the peroxide decomposes so that the amount in the solution while in the recirculating systems is less than in the solution as prepared.

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CIRCUIT OF THYATRON RELAY USED WITH 20 FT/SEC RECIRCULATING SYSTEMS

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Beaker Assembly

Top View
Sample Assembly

Detail of sample assembly

Figure A-0

STATISTICAL TESTING SYSTEM

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Figure A-1

CLASSIFICATION OF CORROSION PITTING SCALE 100X

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Table A-I

STATISTICAL CORROSION TESTS ON 35 ALUMINUM

Run No.	Temp., °C	pH	H ₂ O ₂ , N x 10 ⁴	Chloride ppm	Calcium ppm	Magnesium ppm	Sulfate, ppm	Conductivity Mho/cm x 10 ⁴	Time, Hours	Bicarbonate, ppm	Ave. Rate of Metal Loss µg/cm ² /hr	Notebook No.	N. B. page No.	Attack
S-1	70	7.5	15	1.3	7.5	1.3	100		406		1.473	990	46-49	Less than A-1
S-2	70	7.3	1.4	1.2	2.7	1.4	100		406		11.140	990	50-53	Ditto
S-3	70	7.5	0.4	1.4	1.7	1.5	100		406		1.288	990	54-57	"
S-4	90	7.6	12	1.6	2.5	1.3	100		406		1.338	990	58-61	"
S-5	90	7.6	1.2	1.7	2.7	1.4	100		406		1.365	990	62-65	"
S-6	90	7.6	0.3	1.9	1.7	1.5	100		406		1.292	990	66-69	"
S-7	70	7.7	11	1.5	20.0	7.0	100	2.7	384	103	1.65	990	76-79	Less than A-1
S-8	70	7.7	.33	1.1	20.3	6.4	100	3.0	384	108	1.98	990	84-87	Ditto
S-9	70	7.7	.25	1.5	19.4	6.2	100	3.1	384	107	2.01	990	92-95	"
S-10	90	8.2	10	1.7	20.0	7.0	100	2.7	384	103	1.39	990	100-103	"
S-11	90	8.0	.31	1.3	20.3	6.4	100	3.0	384	108	2.92	990	108-111	"
S-12	90	8.0	.23	1.4	19.4	6.2	100	3.1	384	107	2.47	990	116-119	"
S-13	70	3.3	1.1	1.1	20.0	5.5	90	6.7	409		3.78	990	132-135	Less than A-1
S-14	70	4.2	1.0	1.1	20.0	5.5	90	2.1	409		0.33	990	140-143	Ditto
S-15	70	5.0	0.9	1.2	20.0	5.6	90	1.9	409		.33	990	148-151	"
S-16	90	3.2	.8	1.3	20.0	7.1	90	6.8	409		4.27	990	156-159	C-5, Many Pits
S-17	90	4.2	1.1	1.3	20.0	6.5	90	2.1	409		.76	990	164-167	Less than A-1
S-18	90	5.0	0.8	1.3	20.0	6.5	90	1.9	409		.31	990	172-175	Ditto
S-19	70	6.5	0.55	1.3	20	6	90	1.8	400		.29	316 B	6-9	Less than A-1
S-20	70	6.8	.25	1.3	20	6	90	1.7	400		.28	316 B	14-17	Ditto
S-21	70	7.6	.25	1.1	20	6	90	1.9	400		.67	316 B	22-25	"
S-22	90	6.7	.25	1.2	20	6	90	1.8	400		.23	316 B	30-33	"
S-23	90	6.8	.25	1.2	20	6	90	1.8	400		.49	316 B	38-41	"
S-24	90	7.6	.25	1.1	20	6	90	1.9	400		1.12	316 B	46-49	"

*The attack is described by indicating the size of the pits found, using letters and numerals referring to figure , page .

11-6-8

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Table A-II

STATISTICAL CORROSION TESTS ON 23 ALUMINUM

Run No.	Temp., °C	pH	H ₂ O ₂ , N x 10 ⁴	Chloride ppm	Calcium ppm	Magnesium ppm	Sulfate ppm	Conductivity, Mho/cm x 10 ⁴	Calcium ppm	Time, Hours	Copper ppm	Notebook No.	N. B. Page No.	Attack
S-25	70	6.7	1.0	1.0	20	6	90	1.7	1	400		316 B	56-59	Less than A-1
S-26	70	6.7	1.0	1.0	20	6	90	1.8	4	400		316 B	64-67	Ditto
S-27	70	6.8	1.0	1.0	20	6	90	1.9	10	400		316 B	72-75	"
S-28	90	6.8	1.0	1.0	20	6	90	1.9	1	400		316 B	80-83	A-2, few pits
S-29	90	6.8	1.0	1.0	20	6	90	1.9	4	400		316 B	88-91	B-2, several pits
S-30	90	6.8	1.0	1.0	20	6	90	1.9	10	400		316 B	96-99	B-3, few pits
S-31	90	6.7	1.0	1.0	20	6	90	3.6		400	0.05	316 B	154-157	Less than A-1
S-32	70	6.8	1.0	1.0	20	6	90	3.6		400	.05	316 B	160-163	Ditto
S-33	90	6.8	1.0	1.0	20	6	90	3.6		400	.08	316 B	166-169	"
S-34	70	6.8	1.0	1.0	20	6	90	3.6		400	.08	316 B	172-175	"
S-35	90	6.7	1.0	1.0	20	6	90	3.6		400	.13	316 B	178-181	"
S-36	70	6.7	1.0	1.0	20	6	90	3.6		400	.13	316 B	184-187	"
S-37	90	6.7		5	20	6	90			168		780 B	4-7	Less than A-1
S-38 ^o	90	6.7		5	20	6	90			168		780 B	8-11	Ditto
S-39	70	6.7		5	20	6	90			168		780 B	12-15	"
S-40 ^o	70	6.7		5	20	6	90			168		780 B	16-19	"
S-41	90	6.7		5	20	6	90			336		780 B	22-25	"
S-42 ^o	90	6.7		5	20	6	90			336		780 B	26-29	"
S-43	70	6.7		5	20	6	90			336		780 B	30-33	"
S-44 ^o	70	6.7		5	20	6	90			336		780 B	34-37	"
S-45	90	6.7		5	20	6	90			504		780 B	40-43	"
S-46 ^o	90	6.7		5	20	6	90			504		780 B	44-47	"
S-47	70	6.7		5	20	6	90			504		780 B	48-51	"
S-48 ^o	70	6.7		5	20	6	90			504		780 B	52-55	"
S-49	90	6.7		5	20	6	90			672		780 B	58-61	"
S-50 ^o	90	6.7		5	20	6	90			672		780 B	62-65	"
S-51	70	6.7		5	20	6	90			672		780 B	66-69	"
S-52 ^o	70	6.7		5	20	6	90			672		780 B	70-73	"

^oNo stirring used in these runs

SECRET

849-115

STATISTICAL CORROSION TESTS ON 2S ALUMINUM

Run No.	Temp., °C	pH	H ₂ O ₂ , N x 10 ⁴	Chloride ppm	Calcium ppm	Magnesium ppm	Sulfate ppm	Potassium Dichromate ppm	Aluminum Alloy Used	Time, Hours	Notebook No.	N. B. Page No.	Attack
S-53	70	6.5	.5	1	20	6	90	2 ^a	2-S	400	780 B	146-149	<A-1
S-54	85	6.5	.5	1	20	6	90	2 ^a		400	780 B	152-155	<A-1
S-55	70	6.5	.5	1	20	6	90	4 ^a		400	780 B	158-161	<A-1
S-56	85	6.5	.5	1	20	6	90	4 ^a		400	780 B	164-167	<A-1
S-57	70	6.5	.5	1	20	6	90	8 ^a		400	780 B	170-173	<A-1
S-58	85	6.5	.5	1	20	6	90	8 ^a		400	780 B	176-179	<A-1
S-59	85	6.5	.2	1.0	20	6	90		2-S	2250	780 B	136-139	C-1
S-60	85	6.5	.2	1.0						2250	780 B	140-143	C-1
S-61	70	5.5	1	1	20	6	90	2	2-S	400	1173 B	38-41	<A-1
S-62	70	7.5	1	1	20	6	90	2		400	1173 B	44-47	Ditto
S-63	70	8.5	1	1	20	6	90	2		400	1173 B	32-35	"
S-64	85	5.5	1	1	20	6	90	2		400	1173 B	56-59	"
S-65	85	7.5	1	1	20	6	90	2		400	1173 B	50-53	"
S-66	85	8.5	1	1	20	6	90	2		400	1173 B	62-65	"
S-67	70	5.5	1	1	20	6	90	4		400	1173 B	68-71	"
S-68	85	5.5	1	1	20	6	90	4		400	1173 B	74-77	"
S-69	70	7.5	1	1	20	6	90	4		400	1173 B	80-83	"
S-70	85	7.5	1	1	20	6	90	4		400	1173 B	86-89	"
S-71	70	8.5	1	1	20	6	90	4		400	1173 B	92-95	"
S-72	85	8.5	1	1	20	6	90	4		400	1173 B	98-101	"
S-73	70	5.5	1	1	20	6	90	8		400	1173 B	110-113	"
S-74	70	7.5	1	1	20	6	90	8		400	1173 B	116-119	"
S-75	70	8.5	1	1	20	6	90	8		400	1173 B	104-107	"
S-76	85	5.5	1	1	20	6	90	8		400	1173 B	128-131	"
S-77	85	7.5	1	1	20	6	90	8		400	1173 B	122-125	"
S-78	85	8.5	1	1	20	6	90	8		400	1173 B	134-137	"
S-79	70	5.5	.2	1	20	6	90		2S-72S	400	1173 B	140-143	<A-1
S-80	70	6.5	.2	1	20	6	90		2S-72S	400	1173 B	146-149	"
S-81	70	7.5	.2	1	20	6	90		2S-72S	400	1173 B	152-155	"
S-82	85	5.5	.2	1	20	6	90		2S-72S	400	1173 B	158-161	"
S-83	85	6.5	.2	1	20	6	90		2S-72S	400	1173 B	164-167	"
S-84	85	7.5	.2	1	20	6	90		2S-72S	400	1173 B	170-173	"

^aNa₂Cr₂O₇ · 2H₂O used. Molecular weight nearly the same as K₂Cr₂O₇.

8-11-64-8

Definitions for symbols appearing in tables A-IV through A-XXI:

- G The gain in weight per unit area of an uncleaned sample.
- L The metal lost per unit area by a sample. Calculated by:
(initial weight minus final cleaned weight) divided by
initial area.
- C Coat weight per unit area. Calculated by subtracting the
cleaned sample weight from the uncleaned sample weight and
dividing by the initial area.
- G' (for point n) = G' (for point n-1) + $D_{m-1,n}$
- $D_{m-1,n}$ The average gain in weight per unit area of all the
uncleaned specimens on test during the period from
point n-1 to point n.
- $L' = \frac{G'}{(C/L)_{avg} - 1}$ (derivation on page 72)
- $(C/L)_{avg}$ The average of all the individually determined values
of C/L for any run.

Table A-IV

STATIC TESTS ON 2S ALUMINUM - RUN B-1

Conditions: 60°C, 1.9 ppm Cl⁻, 1.2x10⁻⁴ NH₂O₂, pH 6.6

Sheet Wet-Ground On 240 Emery Paper, Then Pre-Cleaned in Stripping Solution

All Units mg/dm²

Sample No. Time, Hours	Sample Weight Change, G						G'	L'
	20	21	22	23	24	Average		
65	9.6	10.9	10.0	9.4	11.1	10.2	10.2	7.4
157		12.5	11.6	10.8	12.7	11.9	11.8	8.6
259			12.4	11.6	13.5	12.5	12.6	9.1
363				11.2	13.5	12.4	12.4	9.0
446					13.5	13.5	12.4	9.0
Coat Weight, C	15.8	21.5	21.3	19.8	23.3			
Metal Lost, L	6.2	9.5	8.9	8.6	9.8			
C/L	2.55	2.26	2.40	2.30	2.38	2.38		

Definitions of symbols used are given on page 117

Notebook Reference: No. 461 p. 25

Sheet wet ground on 240 emery paper, precleaned in stripping solution ($\text{HPO}_4\text{-CrO}_3$)

60°C $1.2 \times 10^{-4} \text{ N } \text{H}_2\text{O}_2$
 1.9 ppm Cl^- pH 6.6

Figure A2

STATIC TESTS ON 2S ALUMINUM - RUN B-1

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611-648

Table A-7

STATIC TESTS ON 2S ALUMINUM - RUN B-2
 Conditions: 60°C, 1.9 ppm Cl⁻, 1.2×10^{-4} NH₂O₂, pH 6.6
 Sheet Pre-Cleaned In Stripping Solution

All Units mg/dm²

Sample No. Time, Hours	Sample Weight Change, G						G'	L'
	30	31	32	33	34	Average		
66	10.1	9.8	9.0	9.0	9.4	9.5	9.5	6.5
158		10.5	10.0	10.0	10.7	10.3	10.5	7.2
260			10.5	10.9	11.7	11.0	11.3	7.7
364				10.6	11.3	11.0	10.9	7.5
447					11.6	11.6	11.2	7.7
Coat Weight, C	16.0	17.6	17.6	17.7	22.0			
Metal Lost, L	- 5.9	- 7.1	- 7.1	- 7.1	-10.4			
C/L	2.72	2.48	2.48	2.50	2.12	2.45		

Notebook Reference: No. 461 pgs. 96, 111, 124

Definition of symbols used given on page 117

~~SECRET~~

S-49-120

Weight change, mg/cm²

Sheet precleaned in stripping solution ($H_3PO_4-CrO_3$)

60°C
1.8 ppm Cl^-

$1 \times 10^{-4} N H_2O_2$
pH 6.6

Figure A3

STATIC TESTS ON 2S ALUMINUM - RUN B-2

A-49-121

Table A-VI

STATIC TESTS ON 2S ALUMINUM - RUN B-3
Conditions: 60°C, 1.9 ppm Cl⁻, 1.2×10^{-4} NH₂O₂, pH 6.6
Sheet Untreated

All Units mg/dm²

Sample No. Time Hours	Sample Weight Change, G						G'	L'
	35	36	37	38	39	Average		
65	15.1	22.7	22.7	22.9	21.9	21.1	21.1	12.3
157		27.8	27.7	28.3	26.3	27.5	26.1	15.2
259			29.6	30.0	28.2	29.3	27.9	16.2
363				30.9	29.0	30.0	28.6	16.6
446					29.8	29.8	29.4	17.2
Coat Weight, C	23.6	46.4	48.2	51.0	48.9			
Metal Lost, L	- 8.5	-18.6	-18.6	-20.1	-19.1			
C/L	2.78	2.49	2.59	2.85	2.87	2.72		

Notebook Reference: No. 461 pgs. 111, 121

Definition of symbols used given on page 117~~SECRET~~

S-49-122

Ordinary Sheet

60°C
1.8 ppm Cl⁻

1.0×10^{-4} H₂O₂
pH 6.6

Figure A-4

STATIC TESTS ON 2S ALUMINUM - RUN B-3

~~SECRET~~

Table A-VII

STATIC TESTS ON 2S ALUMINUM - RUN B-4
 Conditions: 60°C, 1.9 ppm Cl⁻, 1.2x10⁻⁴ NH₂O₂, pH 6.6
 Sheet Cleaned In 5% NaOH at 40°C for 5 Minutes

All Units mg/dm²

Sample No. Time, Hours	Sample Weight Change, G						G'	L'
	25	26	27	28	29	Average		
70	12.4	24.4	12.8	20.4	23.6	18.7	24.4	17.0
184			13.8	23.3	26.4	21.2	26.6	18.5
283					28.0	28.0	28.2	19.5
Coat Weight, C	23.0	40.8	22.8	38.0	47.5			
Metal Lost, L	-10.6	-16.4	- 9.0	-14.7	-19.5			
C/L	2.17	2.49	2.54	2.58	2.44	2.44		

Definition of symbols used given on page 117

S-49-124

Sheet Chemically Cleaned in NaOH

60°C
19 ppm Cl⁻

1.2×10^{-4} N H₂O₂
pH 6.6

Figure A-5

STATIC TESTS ON 2S ALUMINUM - RUN E-6

A-49-125

Table A-VIII

STATIC TESTS ON 2S ALUMINUM - RUN B-5
 Conditions: 60°C, 19 ppm Cl⁻, 1.2x10⁻⁴ NH₂O₂, pH 6.6
 Sheet Wet Ground On 240 Emery Paper

All Units mg/dm²

Sample No. Time Hours	Sample Weight Change, G						G'	L'
	40	41	42	43	44	Average		
71	25.1	21.8	42.3	38.7	40.4	33.6	33.6	22.4
141		27.0	46.3	42.9	44.6	40.2	38.0	25.3
234			47.5	44.5	46.4	46.1	39.5	26.4
297				45.3	46.8	46.1	40.1	26.8
376					46.8	46.8	40.1	26.8
Coat Weight, G	43.0	45.0	77.9	75.3	77.0			
Metal Lost, L	-17.9	-18.0	-30.4	-30.0	-30.2			
C/L	2.40	2.50	2.56	2.51	2.55	2.50		

Notebook Reference: No. 461 pgs. 117, 120

Definition of symbols used given on page 117

~~SECRET~~

Sheet Wet Ground on 240 Emery Paper

60°C
1.9 ppm Cl⁻

1.5×10^{-4} N H₂O₂
pH 6.2

Figure A-6

STATIC TESTS ON 2S ALUMINUM - RUN B-5

-128-

~~SECRET~~

8-49-127

Table A-IX

STATIC TESTS ON 2S ALUMINUM - RUN B-6
 Conditions: 60°C, 1.9 ppmCl⁻, 1.2x10⁻⁴ NH₂O₂ pH 6.6
 Sheet Wet Ground On 240 Emery Paper

All Units mg/dm²

Sample No. Time, Hours	Sample Weight Change, G												
	45	56	47	48	49	50	51	52	53	54	Average	G'	L'
72	15.8	17.7	18.0	17.1	18.0	16.4	15.8	16.1	15.0	13.9	16.4	16.4	14.2
165		19.8	20.1	20.0	20.7	19.4	18.2	18.1	17.5	16.4	18.9	18.9	16.4
229			21.8	21.0	22.3	21.2	19.4	19.3	19.3	17.8	20.3	20.4	17.7
308				21.2	22.7	21.2	19.4	19.5	19.9	17.6	20.2	20.6	17.9
409					23.3	22.6	20.2	20.7	20.9	18.6	21.1	21.6	18.8
509						26.0	23.4	23.9	24.0	21.6	23.8	24.8	21.6
581							23.8	25.1	25.0	22.2	24.0	25.6	22.3
675 1/2								25.9	26.0	23.4	25.1	26.6	23.1
775									26.6	22.8	24.7	26.6	23.1
864 1/2										22.8	24.7	26.6	23.1
Coat Weight,C	28.8	35.5	40.4	40.4	44.4	46.1	46.0	50.4	50.2	44.0			
Metal Lost,L	-13.0	-15.7	-18.6	-19.2	-21.0	-20.1	-22.2	-24.6	-24.3	-20.5			
C/L	2.22	2.26	2.17	2.10	2.11	2.29	2.07	2.04	2.06	2.14	2.15		

Notebook Reference: No. 461 pgs. 117, 122, 123

Definition of symbols used given on page 117

~~SECRET~~

8-49-128

Ordinary Sheet Wet Ground on 240 Emery Paper

95°C
2 ppm Cl⁻

1×10^{-4} N H₂O₂
pH 6.6

Figure A-7

STATIC TESTS ON 2S ALUMINUM-RUN B-6

Table A X

STATIC TESTS ON 2S ALUMINUM - RUN B-7
 Conditions: 60°C, 1.9 ppm Cl⁻, 1.2×10^{-4} NH₂O₂ pH 6.6
 Untreated Sheet

Sample No. Time, Hours	All Units mg/dm ² Sample Weight Change, G										Average	G'	L'
	60	61	62	63	64	65	66	67	68	69			
96	11.3	13.4	11.2	11.2	11.8	12.0	11.8	12.2	11.0	10.2	11.6	11.6	10.4
190		12.8	11.0	11.2	11.6	11.8	11.6	12.2	10.8	10.0	11.4	11.4	10.4
285			12.2	12.4	13.0	13.0	12.8	13.4	12.0	11.4	12.5	12.6	11.2
375				12.0	12.8	12.8	12.8	13.2	11.6	11.2	12.3	12.4	11.1
477					12.6	12.6	12.6	12.8	11.6	11.0	12.2	12.2	11.0
563						13.4	13.4	13.8	12.2	11.6	12.9	13.0	11.6
653							13.6	13.6	11.8	11.2	12.6	12.7	11.2
747								13.6	11.8	11.6	12.3	12.8	11.4
861									11.6	11.2	11.4	12.5	11.2
975										11.3	11.3	12.6	11.2
Coat Weight, G	22.0	20.5	20.0	22.9	26.6	24.5	25.8	26.6	24.3	28.3			
Metal Lost, G	-10.7	-7.7	-7.8	-10.9	-14.0	-11.1	-12.2	-13.0	-12.7	17.0			
C/L	2.06	2.66	2.56	2.10	1.90	2.21	2.13	2.04	1.91	1.66	2.12		

Definition of symbols used given on page 117

Notebook Reference: No. 461 pg. 118

8-49-130

-1.2-

Untreated Sheet

95°C
1.7 ppm Cl⁻

9.2×10^{-4} N H₂O₂
pH 6.6

Figure A-8

STATIC TESTS ON 2S ALUMINUM - RUN B-7

8-49-131

Table A-XI

STATIC TESTS ON 2S ALUMINUM - RUN B 2
 Conditions: 60°C, 1.9 ppm Cl⁻, 1.2×10^{-4} M O₂ pH 6.6
 Untreated Sheet

Sample No. Time, Hours	All Units mg/dm ² Sample Weight Change, G											Average	G'	L'
	70	71	72	73	74	75	76	77	78	79				
88	8.2	10.4	10.6	10.4	9.3	9.9	10.0	10.4	11.1	9.5	10.0	10.0	9.6	
182		10.2	10.4	10.0	9.3	9.5	10.0	10.2	11.1	9.3	10.0	9.8	9.4	
277			11.2	11.0	9.9	10.5	10.4	11.2	11.9	9.9	10.7	10.6	10.2	
367 1/2				10.8	9.7	10.1	10.6	11.0	11.9	9.7	10.5	10.8	10.4	
469 1/2					9.1	9.7	9.8	10.4	11.5	9.3	10.0	11.1	10.7	
555 1/2						10.7	10.8	11.2	12.3	10.5	11.1	12.1	11.6	
645 1/2							10.8	11.0	12.5	10.5	11.2	12.1	11.6	
740								11.6	12.3	10.3	11.4	12.2	11.7	
854									12.3	10.1	11.2	12.1	11.6	
973														
Coat Weight, G	18.6	18.7	19.0	20.1	18.2	22.3	21.2	22.6	24.5	23.1				
Metal Lost, L	-10.4	- 8.5	- 7.8	- 9.3	- 9.1	-11.6	-10.4	-11.0	-12.2	-13.0				
C/L	1.79	2.20	2.44	2.16	2.00	1.92	2.04	2.05	2.01	1.78	2.04			

Notebook Reference: No. 461 pg. 119

Definition of symbols used given on page 117

8-49-132

Untreated Sheet

95°C
Cl⁻ None

9.5×10^{-4} N H₂O₂
pH 6.6

Figure A-9

STATIC TESTS ON 2S ALUMINUM - RUN E-8

8-49-133

Table A-XII

STATIC TESTS ON 2S ALUMINUM - RUN B-9
 Conditions: 60°C, 1.9 ppm Cl⁻, 1.2x10⁻⁴ NH₂O₂ pH 6.6
 Untreated Sheet

Sample No. Time, Hours	All Units mg/dm ²											Average	C'	L'
	Sample Weight Change, G													
	80	81	82	83	84	85	86	87	88	89				
89 1/2	31.5	31.2	26.5	31.8	26.0	23.7	26.7	13.6	29.0	25.9	26.6	26.6	19.5	
184 1/2		34.5	30.8	35.9	29.7	28.0	29.8	17.3	32.5	29.4	29.8	30.3	22.1	
274			30.8	36.1	29.7	27.8	30.0	17.5	32.5	29.4	29.2	30.3	22.1	
375				35.5	29.5	28.2	29.8	17.3	32.7	29.6	29.0	30.4	22.1	
460 1/2					30.4	29.2	31.0	18.5	33.9	30.6	28.9	31.6	23.0	
550 1/2						29.2	31.0	18.5	34.1	30.6	28.7	31.6	23.0	
644 1/2							31.2	18.5	34.1	30.8	28.6	31.7	23.0	
759								18.7	34.3	31.0	28.0	31.9	23.0	
878									34.7	31.2	32.9	31.8	23.0	
972										31.8	31.8	32.4	23.0	
Coat Weight, C	52.0	55.8	57.1	60.5	49.9	54.8	5.1	63.5	56.1	51.9				
Metal Lost, L	-20.5	-21.3	-26.3	-25.0	-12.5	-25.6	-20.0	-44.8	-21.4	-20.1				
C/L	2.54	2.62	2.17	2.42	2.56	2.14	2.56	1.42	2.62	2.58	2.36			

Definition of symbols used given on page 117

Notebook Reference: No. 461 pg. 125

8-49-134

Untreated Sheet

70°C
1.8 ppm Cl⁻

1.2×10^{-4} N H₂O₂
pH 6.5

Figure A-10

STATIC TESTS ON 2S ALUMINUM - RUN B-9

8-49-135

Table XIII

STATIC TESTS ON 2S ALUMINUM - RUN B-10
 Conditions: 60°C, 1.9 ppm Cl⁻, 1.2x10⁻⁴ NH₂O₂ pH 6.6
 Untreated Sheet

Sample No. Time, Hours	All Units mg/dm ² Sample Weight Change, G												
	90	91	92	93	94	95	96	97	98	99	Average	G'	I'
121	13.6	13.3	16.3	13.7	15.3	14.6	14.7	13.8	14.9	15.9	14.6	14.6	13.5
213		12.5	15.7	12.7	14.5	13.6	13.9	13.2	13.7	15.3	13.9	13.8	12.8
338			17.3	13.5	14.5	14.6	14.5	13.6	14.5	15.9	14.8	14.5	13.6
428				13.3	14.9	14.6	14.5	13.6	15.7	16.3	14.7	14.7	13.6
522 1/2					15.9	15.6	15.5	14.6	15.9	17.1	15.8	15.5	14.3
637						15.6	15.5	14.6	15.7	16.9	15.7	14.7	13.6
751 1/2							15.9	15.0	16.1	17.3	16.1	15.1	14.0
865 1/2								15.0	16.3	17.5	16.3	15.2	14.1
959									16.7	18.1	17.4	15.7	14.5
1047										18.3	18.3	15.9	14.7
Coat Weight,C	24.7	23.5	30.9	25.8	32.4	29.1	31.5	29.0	32.2	40.7			
Metal Lost,L	-11.1	-11.0	-13.6	-12.5	-16.5	-13.5	-15.6	-14.0	-15.5	-22.4			
C/L	2.22	2.14	2.27	2.06	1.96	2.16	2.02	2.07	2.08	1.82	2.08		

Notebook Reference: No. 461 pg. 125

Definition of symbols used given on page 117

8-49-136

UNCLASSIFIED

Untreated Sheet

95°C
2.2 ppm Cl⁻

H₂O₂ None
pH 6.6

Figure A-11

STATIC TESTS ON 2S ALUMINUM - RUN B-10

Table XIV

STATIC TESTS ON 28 ALUMINUM - RUN B-11
 Conditions: 60°C, 1.9 ppm Cl⁻, 1.2x10⁻⁴ NH₃ O
 Untreated Sheet

Sample No. Time, Hours	All Units mg/dm ² Sample Weight Change, G												
	100	101	102	103	104	105	106	107	108	109	Average	G'	L'
94 1/2	10.4	10.0	10.4	10.6	10.0	10.4	10.0	10.3	10.4	10.8	10.3	10.3	9.6
196		10.6	10.6	10.2	10.2	10.8	10.0	10.5	10.4	10.6	10.4	10.4	9.7
280 1/2			12.0	12.3	11.6	11.8	11.9	12.8	12.9	12.7	12.2	12.3	11.5
370 1/2				11.5	11.6	12.0	11.1	12.0	11.7	11.7	11.7	11.7	10.9
465					11.8	12.2	11.1	11.8	11.9	11.9	11.6	11.8	11.0
579 1/2						12.4	11.3	12.0	11.9	12.1	11.9	12.0	11.2
694							11.5	12.0	11.9	12.1	11.9	12.1	11.3
787 1/2								12.2	12.1	12.3	12.2	12.3	11.5
875 1/2									12.9	13.1	13.0	13.1	12.2
963 1/2										13.3	13.3	13.3	12.4
Coat Weight, C	19.5	19.4	21.6	22.1	22.6	24.6	23.6	24.8	24.2	28.4			
Metal Lost, L	- 9.1	- 8.8	- 9.6	-10.6	-10.8	-12.2	12.1	12.6	11.3	15.1			
C/L	2.14	2.21	2.25	2.08	2.09	2.03	1.95	1.97	2.14	1.88	2.07		

Notebook Reference: No. 461 Pg. 126

Definition of symbols used given on page 117

8-49-138

SECRET

Untreated Sheet

95°C

Cl⁻ None

H₂O₂
pH

None

6.5

Figure A-12

STATIC TESTS ON 2S ALUMINUM - RUN B-11

-143-

8-49-139

Table XV

STATIC TESTS ON 2S ALUMINUM - RUN B-12
 Conditions: 60°C, 1.9 ppm Cl⁻, 1.2x10⁻⁴ NH₂O₂ pH 6.6
 Untreated Sheet

All Units mg/dm²

Sample No. Time, Hours	Sample Weight Change, G											Average	G'	L'
	110	111	112	113	114	115	116	117	118	119				
.94 1/2	10.4	10.2	10.6	11.1	12.2	10.8	10.9	11.3	10.2	10.7	10.8	10.8	11.2	
.195		10.4	10.8	11.1	12.0	11.0	11.1	11.1	10.2	10.7	10.9	10.8	11.2	
.297 1/2			11.8	11.9	13.2	11.8	11.9	12.3	11.0	9.5	11.7	11.5	12.0	
370				12.5	13.2	12.0	12.1	12.5	11.0	9.5	11.8	11.7	12.2	
.467					13.2	11.8	12.1	12.5	11.0	9.1	11.6	11.6	12.1	
.582						12.4	12.3	13.1	11.1	9.1	11.6	11.9	12.4	
.696							12.3	13.1	11.3	9.1	11.4	11.9	12.4	
.789 1/2								13.3	11.3	9.9	11.5	12.2	12.7	
.877 1/2									11.9	10.3	11.1	12.7	13.2	
965 1/2										10.3	10.3	12.7	13.2	
Coat Weight, C	19.2	20.6	23.1	23.6	24.9	25.8	25.6	26.2	30.2	27.6				
Metal Lost, L	- 8.8	-10.2	-11.3	-11.1	-11.7	-13.4	-13.3	-12.9	-18.3	-17.3				
C/L	2.18	2.02	2.04	2.12	2.13	1.93	1.93	2.03	1.65	1.60	1.96			

Notebook Reference: No. 461 pg. 127
 Definition of symbols used given on page 117

8-49-140

~~SECRET~~

Untreated Sheet

95°C

Cl⁻ None

1.4×10^{-4} N H₂O₂
pH 6.5

Figure A-13

STATIC TESTS ON 2S ALUMINUM - RUN B-12

141-64-8

Table XVI

STATIC TESTS ON 2S ALUMINUM - RUN B-13
 Conditions: 60°C, 1.9 ppm Cl⁻, 1.2x10⁻⁴ NH₂O₂ pH 6.6
 Untreated Sheet

Sample No. Time, Hours	All Units mg/dm ² Sample Weight Change, G										Average	G'	L'
	120	121	122	123	124	125	126	127	128	129			
91	30.1	22.0	14.9	14.4	24.0	15.2	31.8	29.6	26.4	27.1	23.6	23.6	15.5
182		27.8	18.2	15.0	28.8	19.1	35.3	34.6	30.6	32.1	26.8	27.6	18.2
311			19.7	17.9	31.9	21.0	37.0	36.9	32.1	32.7	28.7	29.5	19.4
392				18.9	32.9	21.6	37.8	38.1	32.9	36.2	31.2	30.8	20.3
464					34.1	22.4	38.6	38.7	33.9	37.0	34.1	31.7	20.8
572						22.4	38.8	39.1	33.9	37.0	34.2	31.8	20.9
668							38.0	38.3	34.7	37.8	37.2	31.8	20.9
784								39.3	36.0	39.0	38.1	33.0	21.7
876									36.0	39.2	37.6	33.1	21.8
968										39.8	39.8	33.7	22.2
Coat Weight, C	49.5	44.8	33.6	37.8	54.3	40.9	62.0	66.0	56.4	60.6			
Metal Lost, L	19.4	17.0	13.9	18.9	20.2	18.5	24.0	26.7	20.4	20.8			
C/L	2.55	2.64	2.42	2.00	2.69	2.21	2.58	2.47	2.76	2.92	2.52		

Notebook Reference: No. 461 pg. 128

Definition of symbols used given on page 1.7

Untreated Sheet

73°C
1.4 ppm Cl⁻

1.2×10^{-4} H₂O₂
pH 6.4

Figure A-14

STATIC TESTS ON 2S ALUMINUM - RUN B-13

Table XVII

STATIC TESTS ON 2S ALUMINUM - RUN B-14
 Conditions: 60°C, 1.9 ppm Cl⁻, 1.2x10⁻⁴ NH₂O₂ pH 6.6
 Untreated Sheet

Sample No. Time, Hours	All Units mg/dm ²											G'	L'
	Sample Weight Change, G										Average		
	130	131	132	133	134	135	136	137	138	139			
92	34.7	35.8	34.9	34.5	34.3	33.0	32.0	35.8	35.3	36.2	35.2	35.2	21.7
182		38.7	37.8	37.4	38.2	37.0	39.5	39.3	38.4	39.3	38.4	38.4	23.7
297			39.3	39.1	40.1	38.5	41.0	40.5	40.1	41.0	40.0	40.0	24.7
389				38.3	40.9	39.3	41.8	41.1	40.9	41.8	40.6	40.6	25.1
461					41.7	39.9	42.6	42.3	41.9	42.6	41.8	41.5	25.6
549						40.5	42.4	42.5	41.9	43.0	42.1	41.7	25.8
645							41.6	41.5	41.1	42.0	41.6	40.8	25.2
764								42.7	42.5	43.3	42.8	41.1	25.4
855									42.5	43.1	42.8	41.0	25.3
946										44.3	44.3	42.3	26.1
Coat Weight, G	57.1	60.9	63.1	65.8	65.7	65.6	67.7	68.95	67.9	71.3			
Metal Lost, L	-22.4	-22.2	-23.8	-27.5	-24.0	-25.1	-26.1	-26.2	-25.4	-27.0			
C/L	2.55	2.74	2.65	2.39	2.74	2.62	2.60	2.63	2.67	2.64	2.62		

Notebook Reference: No. 461 pg. 129

Definition of symbols used given on page 117

~~SECRET~~

Untreated Sheet

72°C
Cl⁻ None

1.4×10^{-4} N H₂O₂
pH 6.4

Figure A-15

STATIC TESTS ON 2S ALUMINUM - RUN B-14

Table XVIII

STATIC TESTS ON 2S ALUMINUM - RUN B-15
 Conditions: 60°C, 1.9 ppm Cl⁻, 1.2×10^{-4} NH₂O₂ pH 6.6
 Untreated Sheet

Sample No. Time, Hours	All Units mg/dm ² Sample Weight Change, G										Average	G'	L'
	140	141	142	143	144	145	146	147	148	149			
68 1/2	13.9	15.3	13.4	14.6	14.0	13.2	15.7	15.4	14.0	14.0	14.4	14.4	10.7
159		16.4	14.7	15.4	14.6	13.6	16.5	16.2	14.6	15.0	15.2	15.2	11.3
273 1/2			15.6	16.4	15.4	14.0	17.7	17.4	14.8	15.8	15.9	16.0	11.9
365				17.2	16.2	15.0	18.9	18.6	15.8	16.6	16.9	17.0	12.6
453					17.0	15.4	19.55	19.2	16.4	17.4	17.5	17.6	13.0
540 1/2						15.0	19.9	19.6	16.6	17.4	17.7	17.8	13.2
636 1/2							18.9	18.8	15.8	16.6	17.5	17.0	12.6
753								20.0	16.8	17.4	18.1	18.0	13.3
845									16.6	17.4	17.0	17.9	13.3
936										17.8	17.8	18.3	13.6
Coat Weight, C	24.5	27.3	26.3	29.1	28.7	27.1	36.3	35.4	28.3	31.3			
Metal Lost, L	10.6	10.9	10.7	11.9	11.7	12.1	17.4	15.4	11.7	13.5			
C/L	2.31	2.50	2.46	2.44	2.45	2.24	2.08	2.30	2.42	2.32	2.35		

Notebook Reference: No. 461 pg. 129

Definition of symbols used given on page 117

~~SECRET~~

8-49-146

Untreated Sheet

72°C
2.1 ppm Cl⁻

13.2×10^{-4} N H₂O₂
pH 6.4

Figure A-16

STATIC TESTS ON 2S ALUMINUM - RUN B-15

-847-

SECRET

~~SECRET~~

Table XIX

STATIC TESTS ON 2S ALUMINUM - RUN B-16
 Conditions: 60°C, 1.9 ppm Cl⁻, 1.2x10⁻⁴ NH₂O₂ pH 6.6
 Untreated Sheet

All Units mg/dm²

Sample No. Time, Hours	Sample Weight Change, G											G'	J'
	150	151	152	153	154	155	156	157	158	159	Average		
96	10.4	10.0	15.0	10.2	9.7	11.4	9.8	8.9	9.8	9.8	10.5	10.5	9.2
186		10.6	15.8	11.0	10.7	12.2	10.6	9.9	10.8	10.6	11.4	11.3	9.9
274			16.0	10.8	10.9	12.8	11.0	10.1	11.0	10.8	11.7	11.5	10.1
388				11.6	11.1	12.8	11.4	10.5	11.0	10.8	11.3	11.8	10.3
482						12.2	11.0	9.9	10.6	10.6	10.9	11.9	10.9
Coat Weight, C	18.3	23.2	24.0	21.0	24.9	24.5							
Metal Lost, L	- 7.9	-13.2	- 9.0	-10.8	-12.0	-11.8							
C/L	2.32	1.76	2.67	1.94	2.08	2.08					2.14		

Notebook Reference: No. 461 pg. 130

Definition of symbols used given on page 117~~SECRET~~

84-1148

~~SECRET~~

-150-

Untreated Sheet

70°C
Cl⁻ None

1 x 10⁻³ N H₂O₂
pH 6.5

Figure A-17

STATIC TESTS ON 2S ALUMINUM - RUN B-16

~~SECRET~~

641-64-28

~~SECRET~~

Table A-XX

STATIC TESTS ON 2S ALUMINUM - RUN B-17
 Conditions: 60°C, 1.9 ppm Cl⁻, 1.2×10^{-4} NH₂O₂ pH 6.6
 Untreated Sheet

All Units mg/dm²

Sample No. Time, Hours	Sample Weight Change, G											G'	L'
	160	161	162	163	164	165	166	167	168	169	Average		
96	14.5	15.7	14.1	16.0	15.6	15.6	13.3	14.7	13.7	15.4	14.9	14.9	18.4
184		17.0	14.9	18.3	17.7	16.9	14.5	16.4	15.2	16.6	16.4	16.4	20.2
298			14.9	17.9	17.9	17.1	14.7	16.6	15.2	16.6	16.4	16.6	20.5
389				17.7	17.5	16.7	14.1	16.0	15.0	16.4	16.2	16.2	20.0
480					17.9	16.9	14.3	16.6	15.0	16.8	16.3	16.6	20.5
1156						16.7	14.5	16.4	15.0	16.4	15.8	16.4	20.2
Coat Weight, G	29.7	40.9	29.5	35.8	35.7								
Metal Lost, L	-15.2	-25.2	-15.4	-19.8	-20.1								
C/L	1.94	1.62	1.91	1.81	1.77						1.81		

Notebook Reference: No. 461 pg. 130

Definition of symbols used given on page 117~~SECRET~~

2-49-150

Untreated Sheet

95°C
1 ppm Cl⁻

1×10^{-3} N H₂O₂
pH 6.5

Figure A-18

STATIC TESTS ON 2S ALUMINUM - RUN B-17

151-64-8

Table XXI

STATIC TESTS ON 28 ALUMINUM - RUN B-18
 Conditions: 60°C, 1.9 ppm Cl⁻, 1.2x10⁻⁴ NH₂O₂ pH 6.6
 Untreated Sheet

All Units mg/dm²

Sample No. Time, Hours	Sample Weight Change, G											G'	L'
	170	171	172	173	174	175	176	177	178	179	Average		
96	7.0	7.3	7.1	6.3	6.7	7.3	6.8	6.2	7.0	6.5	6.8		
1172		7.4	8.0	6.7	7.5	7.6	7.1	7.0	7.9	6.6	7.3		
Coat Weight, C	25.6												
Metal Lost, L	12.1												
C/L	2.12												

Notebook Reference: No. 461 pg. 131

Definition of symbols used given on page 117~~SECRET~~

-153-

8-49-152

Untreated Sheet

70°C
1 ppm Cl^-

$1 \times 10^{-3} \text{ N } \text{H}_2\text{O}_2$
pH 6.5

Figure A-19

STATIC TESTS ON 2S ALUMINUM - RUN B-18

8-49-15-3

~~SECRET~~

-100-

○ 72S Aluminum
△ 2S Aluminum

$H_2O_2 = 2 \times 10^{-5}$
 $Cr_2O_7 = 5 \text{ ppm}$

Figure A-20

CORROSION OF ALUMINUM ALLOYS IN SIMULATED
RIVER WATER CONTAINING PEROXIDE AND DICHROMATE

~~SECRET~~

8-49-154

~~SECRET~~

8-6

○ 72S Aluminum
△ 2S Aluminum

$H_2O_2 = 2 \times 10^{-5}$
 $Cr_2O_7 = 5 \text{ ppm}$

Figure A-21

CORROSION OF ALUMINUM ALLOYS IN SIMULATED
RIVER WATER CONTAINING PEROXIDE AND DICHROMATE

~~SECRET~~

8-49-155

* Low Ca⁺⁺ & Mg⁺⁺ Conc.
- No - PPM Cl⁻ Conc.

9 FT./SEC.

15 FT./SEC.

20 FT./SEC.

			(C°) 70				(C°) 95				(C°) 70				(C°) 80				(C°) 70				(C°) 80				(C°) 95			
pH	H ₂ O ₂	H ₂ O	ppm CF				ppm CF				ppm CF				ppm CF				ppm CF				ppm CF				ppm CF			
			0	1	2	SPECIAL	0	1	2	SPECIAL	0	1	2	SPECIAL	0	1	2	SPECIAL	0	1	2	SPECIAL	0	1	2	SPECIAL				
3.0 TO 3.9	0	D																												
	10 ⁻⁵	D																												
	10 ⁻⁴	D																												
	10 ⁻³	D																												
4.0 TO 4.8	0	D																												
	10 ⁻⁵	D																												
	10 ⁻⁴	D																												
	10 ⁻³	D																												
4.9 TO 5.3	0	D																												
	10 ⁻⁵	D																												
	10 ⁻⁴	D																												
	10 ⁻³	D																												
5.4 TO 5.8	0	D																												
	10 ⁻⁵	D																												
	10 ⁻⁴	D																												
	10 ⁻³	D																												
5.9 TO 6.3	0	D																												
	10 ⁻⁵	D																												
	10 ⁻⁴	D																												
	10 ⁻³	D																												
6.4 TO 6.8	0	D																												
	10 ⁻⁵	D																												
	10 ⁻⁴	D																												
	10 ⁻³	D																												
6.9 TO 7.3	0	D																												
	10 ⁻⁵	D																												
	10 ⁻⁴	D																												
	10 ⁻³	D																												
7.4 TO 7.8	0	D																												
	10 ⁻⁵	D																												
	10 ⁻⁴	D																												
	10 ⁻³	D																												
7.9 TO 8.3	0	D																												
	10 ⁻⁵	D																												
	10 ⁻⁴	D																												
	10 ⁻³	D																												
8.4 TO 8.8	0	D																												
	10 ⁻⁵	D																												
	10 ⁻⁴	D																												
	10 ⁻³	D																												

INDEX CHART FOR RUNS IN RECIRCULATING SYSTEMS 33-203
Numbers following each run number in 'Special' columns refers to ppm chloride ion. All tests on '28' aluminum unless otherwise stated.

8-49-156

CORROSION TEST RUN

OBJECT:-

To determine the corrosion of 2S aluminum by the following conditions:

CONDITIONS:- (Average throughout run)

pH 5.8

Temp., °C. 70

N H₂O₂ 1.2x10⁻⁵

Velocity 9 ft./sec.

ppm Cl⁻ 0

Hrs. in test 605

Date finished 3-18-43

APPEARANCE:-

Greenish brown streaks and areas, remainder of surface dull, somewhat rough.

CORROSION:-

Wt. of coat, Mg/cm² 0.32

Overall metal lost, µg/cm²/hr

Corrosion rate, µg/cm²/hr. 075 µg(0-600 hrs)

0.61

8-49-157

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: - (Average thruout run)pH 6.0Temp., °C. 95N H₂O₂ 1.6 x 10⁻⁵Vel., ft/sec. 9ppm Cl⁻ 0Hrs. in test 685Date finished 4-20-43APPEARANCE:

Somewhat rough. Brown discoloration though due to oil from stuffing box of pump.

CORROSION:wt. of coat, Mg/cm² 0.30 Overall metal lost,Corrosion rate, µg/cm²/hr 1.13 (0-100 hrs) µg/cm²/hr 0.280.28 (100-300 hrs)0.13 (300-700 hrs)

CORROSION TEST RUN

Run No. 35

Data - N.B.# 290 Page# 136

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: - (average thruout run)

pH 6.1

Temp., °C. 70

N H₂O₂ 2.8×10^{-5}

Vel., ft./sec. 9

ppm Cl⁻ 2.0

Hrs. in test 905

Date Finished 4-15-43

APPEARANCE:

Pinpoint barnacles developed after 65 hours exposure. Isolated pits observed after 380 hours at which time the barnacles were no longer evident. No roughness or discoloration, - dull surface.

CORROSION:

Wt. of coat, Mg/cm² 0.44 Overall metal lost, 0.51 $\mu\text{g/cm}^2/\text{hr}$
Corrosion rate, $\mu\text{g/cm}^2/\text{hr}$. 0.29 (200-600 hrs.)

S-49-159

CORROSION TEST RUN

Data - N.B. # 832 Page # 5

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS : - (Average thruout run)

pH 5.9

Temp., °C. 95

N H₂O₂ 1.4×10^{-5}

Vel., ft./sec. 9

ppm Cl- 2.1

Hrs. in test 656

Date finished 6-3-43

APPEARANCE:

Numerous rough areas of oxide coating of average thickness of .05 mm. Pits in rough areas .05-.10 mm deep, .07-.10 mm diam. Several pits as deep as 0.15 mm. Numerous small black spots 0.01 mm high. First sign of attack 100 hrs.

CORROSION:Wt. of coat, Mg/cm² 1.54Overall metal lost, $\mu\text{g}/\text{cm}^2/\text{hr}$ 1.78Corrosion rate, $\mu\text{g}/\text{cm}^2/\text{hr}$ -1.5 (0-300 hrs.)
0.43 (300-650 hrs.)

S-49-160

CORROSION TEST RUN

Run No. 37Data - N.B.# 290 Page 60OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.0 Temp., °C. 70
N H₂O₂ 4.2×10^{-5} Vel., ft./sec. 9
ppm Cl⁻ 3.8 Hrs. in test 173
ppm Ca⁺⁺ 0 Date finished 2-19-43
ppm SO₄⁼ 0
ppm Mg⁺⁺ 0

APPEARANCE:

Pits: Number None
Depth, mm _____
Diameter at top, mm _____

Color:

Green and brown spotted and streaked, somewhat rough.

CORROSION:Wt. of coat, mg/cm² 1.18Overall metal lost,
μg/cm²/hr. 4.6Corrosion rate, μg/cm²/hr. 1.28

S-49-161

~~SECRET~~

-163-

Run No. 38

Data-N.B. # 290 Page #1

CORROSION TEST RUN

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS:- (Average throughout run)

pH 6.0

Temp., °C. 95

N H₂O₂ 1.8×10^{-5}

Vel., ft./sec. 9

ppm Cl⁻ 3.9

Hrs. in test 681

APPEARANCE:

Date finished 4-17-43

Surface covered with dull green film. Large dark green rough spots.

CORROSION:

Wt. of Coat, Mg/cm² 0.74

Overall metal lost, µg/cm²/hr. 0.72

Corrosion rate, = Initial gain, followed by almost no gain thereafter.

TIME (hours)

~~SECRET~~

S-49-162

~~SECRET~~

-164-

Run No. 39

CORROSION TEST RUN

Data - N.B.# 290 Page 173OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: (Average thruout run)pH 5.9Temp., °C 70N H₂O₂ 2.1x10⁻⁵Vel., ft./sec. 9ppm Cl⁻ 5.5Hrs. in test 524ppm Ca⁺⁺ 0Date finished 5/8/43ppm SO₄⁼ 0ppm Mg⁺⁺ 0APPEARANCE:

Pinpoint barnacles appeared after 40 hours. These developed throughout the run to larger rough spots. The remainder of the surface was smooth and dull.

CORROSION:Wt. of coat, mg/cm² 0.79Overall metal lost,
μg/cm²/hr. 1.30Corrosion rate, μg/cm²/hr. -0.06 ~~SECRET~~

S-49-163

CORROSION TEST RUN

Data - N.B.#290 Page 50

~~SECRET~~OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 5.9

Temp., °C. 95

N H₂O₂ 3.1 X 10⁻⁵

Vel., ft./sec. 7

ppm Cl⁻ 61

Hrs. in test 222

ppm Ca⁺⁺ 0

Date finished 2-15-43

ppm SO₄⁻ 0ppm Mg⁺⁺ 0APPEARANCE:

Pits: Number None
 Depth, mm
 Diameter at top, mm

Color:

Surface rough, gray-green barnacles with brown areas between them.

CORROSION:Wt. of coat, mg/cm² 6.8Overall metal lost,
μg/cm²/hr. 24.0Corrosion rate, μg/cm²/hr. 4.5

S-49-164

CORROSION TEST RUN

Run No. 41

Data - N. B. # 290 Page # 46

OBJECT:

To determine the corrosion of 17ST aluminum at the following conditions:

CONDITIONS: - (Average thruout run)

pH <u>6.1</u>	Temp., °C., <u>94</u>
N H ₂ O ₂ <u>1.0 x 10⁻⁴</u>	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>12.0</u>	Hrs. in test <u>177</u>
	Date finished <u>2-9-43</u>

APPEARANCE:

Large greenish barnacles, areas between covered with small brown specks. Very rough, pitted surface.

CORROSION:

wt. of coat, Mg/cm² 5.46 Overall metal lost, 37.5 µg/cm²/hr.
Corrosion rate, µg/cm²/hr. 9.71 (50-177 hrs)

CORROSION TEST RUN

Run No. 42Data -N.B.# 290 Page 167OBJECT:

To determine the corrosion of 2S aluminum, whose surface has been treated with fuming nitric acid at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>5.8</u>	Temp., °C <u>95</u>
N H ₂ O ₂ <u>0.7x10⁻⁵</u>	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>6.6</u>	Hrs. in test <u>318</u>
ppm Ca ⁺⁺ <u>0</u>	Date finished <u>5/5/43</u>
ppm SO ₄ ⁼ <u>0</u>	Surface treated in fuming HNO ₃ for one hour
ppm Mg ⁺⁺ <u>0</u>	

APPEARANCE:

Large rough green areas, areas and streaks of small brown spots.
First sign of attack after 64 hours. (Very much less attack than untreated aluminum under similar conditions-Run 40)

CORROSION:

Wt. of coat, mg/cm² 3.10

Overall metal lost,
μg/cm²/hr. 7.9

Corrosion rate, μg/cm²/hr. 3.2 (200-300 hrs.)

CORROSION TEST RUN

Run No. 43Data - N.B.# 832 Page 7OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 6.1Temp., °C 95N H₂O₂ 6x10⁻⁵Vel., ft./sec. 9ppm Cl⁻ 3.9Hrs. in test 559Date finished 6/3/43200 ppm NaNO₃APPEARANCE:

Surface covered with very numerous minute bright metallic particles, mostly spherical in shape. No pits or other attack.

CORROSION:Wt. of coat, mg/cm² 0.41Overall metal lost,
µg/cm²/Hr. 1.00Corrosion rate, µg/cm²/hr. -1.4 (0-150 hrs.)
1.2 (200-500 hrs.) ~~SECRET~~

S-49-167

CORROSION TEST RUN

Run No. 44

Data - N.B.# 290 Page 163

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.5 Temp., °C 95
N H₂O₂ 7.3x10⁻⁵ Vel., ft./sec. 9
ppm Cl⁻ 5.9 Hrs. in test 365
Date finished 5/3/43
11.4 ppm Calgon

APPEARANCE:

Some individual pits noticed after first 25 hours. Rapid growth of barnacles after 50 hours. Final appearance: Extremely rough heavy coating of blue-green and white particles--brown undercoating visible in small spots between barnacle coating. Very little metal visible.

CORROSION:

Wt. of coat, mg/cm² 18.5
Corrosion rate, µg/cm²/hr. 22.2

Overall metal lost,
µg/cm²/hr. 61

S-49-168

CORROSION TEST RUN

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>6.1</u>	Temp., °C <u>95</u>
N H ₂ O ₂ <u>9.4x10⁻⁵</u>	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>4.1</u>	Hrs. in test <u>382</u>
ppm Ca ⁺⁺ <u>0</u>	Date finished <u>5/21/43</u>
ppm SO ₄ ⁼ <u>0</u>	3.0 ppm Calgon
ppm Mg ⁺⁺ <u>0</u>	

APPEARANCE:

Evidences of attack after 20 hrs. Final appearance: Large no. of pits 0.7 mm diam. 0.1-0.3 mm deep. Some pits along edge 0.10 mm deep. 50% of surface covered with heavy coating 0.03 mm thick, 30% with light coating. Visible metal very rough.

CORROSION:

Wt. of coat, mg/cm² 9.52

Corrosion rate, µg/cm²/hr. 13

Overall metal lost,
µg/cm²/hr. 35

CORROSION TEST RUN

Ivan No. 46Data - N.B.# 832 Page 10OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>6.2</u>	Temp., °C <u>70</u>
N H ₂ O ₂ <u>1.3x10⁻⁵</u>	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>4.1</u>	Hrs. in test <u>320</u>
ppm Ca ⁺⁺ <u>0</u>	Date finished <u>6/4/43</u>
ppm SO ₄ ⁼ <u>0</u>	3.2 ppm Calgon
ppm Mg ⁺⁺ <u>0</u>	

APPEARANCE:

Spotty, heavy (0.3 mm) white coating and brown, very thin coating covers most of surface. Very little metal visible. Pits, mostly where white coating fell off, very numerous, 0.15-0.30 mm deep, 0.5-0.7 mm diam. First sign of attack after 20 hours.

CORROSION:Wt. of coat, mg/cm² 5.60Overall metal lost,
µg/cm²/hr. 14.9Corrosion rate, µg/cm²/hr. 33.5 (0-160 hrs.)
27.6 (160-320 hrs.)

5-62-170

CORROSION TEST RUN

Run No. 48

Data - N.B.# 290 Page 192

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.1

Temp., °C 80

N H₂O₂ 1.5x10⁻⁵

Vel., ft./sec. 28

ppm Cl⁻ 0

Hrs. in test 418

ppm Ca⁺⁺ 0

Date finished 5/22/43

ppm SO₄⁼ 0ppm Mg⁺⁺ 0APPEARANCE:

Very smooth surface. No evidence of attack. Some tan discoloration.
Ends of samples grooved by sample supports.

CORROSIONWt. of coat, mg/cm² 0.45Overall metal lost,
μg/cm²/hr. 1.34Corrosion rate, μg/cm²/hr. 0.86

S-49-171

CORROSION TEST RUN

Run No. 49

Data - N.B.# 832 Page 38

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH	6.8	Temp., °C	82
N H ₂ O ₂	2.4x10 ⁻⁵	Vel., ft./sec.	38
ppm Cl ⁻	1.07	Hrs. in test	749 3/4
ppm Ca ⁺⁺	0	Date finished	7/14/43
ppm SO ₄ ⁼	0		
ppm Mg ⁺⁺	0		

APPEARANCE:

Some discoloration: a tan stain in small spots. Some pits -0.06mm, deep, numerous smaller pits 0.01 m.m. --somewhat rough. Numerous small scattered lumps of oxide. Enlarging of scratches not removed by polishing.

CORROSION:Wt. of coat, mg/cm² 0.51Overall metal lost,
µg/cm²/hr. 0.95Corrosion rate, µg/cm²/hr. 0.23

CORROSION TEST RUN

Run No. 50

Data - N.B. # 832 Page # 46

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: - (Average thruout run)

pH 6.8

Temp., °C. 94.4

N H₂O₂ 1.5×10^{-4}

Vel., ft./sec. 9

ppm Cl⁻ 1.8

Hrs. in test 559½

Date finished 7-22-43

APPEARANCE:

Dull gray. Much general roughness, very numerous minute pits. Some specks of oxide, pits associated with oxide specks approximately 0.04 mm.

CORROSION:

Wt. of coat, mg/cm² 0.5 Overall metal lost, 1.11 µg/cm²/hr.
Corrosion rate, µg/cm²/hr. 0.11 (250-550 hrs)

~~SECRET~~

-175-

Run No. 51

Corrosion Test Run

Data - N.B. # 832 Page # 37

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: - (Average thruout run)

pH 6.9

Temp., °C. 95

N H₂O₂ 4.7×10^{-4}

Vel., ft./sec. 9

ppm Cl⁻ 1.4

Hrs. in test 629¹

Date finished 7-15-43

APPEARANCE:

Light gray, smooth. Somewhat rough. Some small lumps of oxide.
No pits.

CORROSION:

Wt. of coat, mg/cm² 0.71 Overall metal lost, 1.33 $\mu\text{g/cm}^2/\text{hr.}$
Corrosion rate, $\mu\text{g/cm}^2/\text{hr.}$ 0.12 (0-70 hrs.)
0.25 (70-630 hrs.)

~~SECRET~~

S-49-174

CORROSION TEST RUN

Data - N.B. # 832 Page # 36

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: - (Average thruout run)

pH 6.8

Temp., °C. 95
$$\text{N H}_2\text{O}_2 \quad \underline{1.0 \times 10^{-3}}$$

Vel., ft./sec. 9

ppm Cl⁻ 1.5

Hrs. in test 629

Date finished 7-15-43

APPEARANCE:

Dark gray to black color, adherent coat, spotty, not continuous. Remainder of surface is gray. Somewhat rough. Some pits approximately .01 mm deep: metal in these pits is very bright.

CORRELATION:

Wt. of coat, mg/cm² 0.62 Overall metal lost, 1.32 $\mu\text{g/cm}^2/\text{hr.}$

Corrosion rate, $\mu\text{g/cm}^2/\text{hr.}$ 0.53 (0-250 hrs)
2.25 (250-630 hrs)

S-49-175

CORROSION TEST RUN

Run No 53Data - N.B.# 832 Page 71OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 6.0Temp., °C. 73.8N H₂O₂ 5.5 x 10⁻⁴Vel., ft./sec. 27ppm Cl⁻ 1.2Hrs. in test 570 $\frac{1}{2}$ ppm Ca⁺⁺ 0Date finished 8/4/43ppm SO₄⁼ 0ppm Mg⁺⁺ 0APPEARANCE:Pits: Number One very small pit, some slight general roughness.Depth, mm Diameter at top, mm

Color:

Dark gray, some patches of black deposit, some oxide spots, .2 mm diameter of no appreciable height.

CORROSION:Wt. of coat, mg/cm² .62

Overall metal lost,

μg/cm²/hr. 1.51Corrosion rate, μg/cm²/hr. .41 (0-570 hrs.) ~~SECRET~~

S-49-176

OBJECT:

To determine the corrosion of anodized 2S aluminum at the following conditions:
(Samples made anodes in 15% H_2SO_4 at ca. 30°C for 30 min., then placed in boiling distilled water for 30 minutes)

CONDITIONS: - (Average thruout run)

pH	6.1	Temp., °C	79.9
N H_2O_2	4.7×10^{-4}	Vel., ft./sec.	15
ppm Cl^-	2.2	Hrs. in test	463.5
ppm Ca^{++}	0	Date finished	8/30/43
ppm SO_4^{--}	0	ppm Calgon	2.9
ppm Mg^{++}	0	ppm $NaNO_3$	24.2

APPEARANCE:

75% of surface of 7A and 7B covered with bright metallic globules, remainder dull. Very numerous, minute gold-colored spots. General roughness. 50% of surface of 7C covered with bright metallic globules, remainder covered with oxide coat. General roughness.

CORROSION:

Wt. of coat, mg/cm² 0.29

Overall metal lost,
μg/cm²/hr. 3.33

Corrosion rate, μg/cm²/hr. 6.1 (375-475 hrs.)

CORROSION TEST RUN

Run No. 55Data - N.B.# 832 Page 69OBJECT:

To determine the corrosion of 3S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>6.0</u>	Temp., °C <u>79.8</u>
N H ₂ O ₂ <u>5. 10⁻⁴</u>	Vel., ft./sec. <u>15</u>
ppm Cl ⁻ <u>1.0</u>	Hrs. in test <u>483¹</u>
ppm Ca ⁺⁺ <u>0</u>	Date finished <u>8/4/43</u>
ppm SO ₄ ⁻ <u>0</u>	
ppm Mg ⁺⁺ <u>0</u>	

APPEARANCE:

Spotty light and dark gray, some small pits .01 mm depth, several larger ones, .07 mm depth. Average diam. = .2 mm. Slightly rough.

CORROSION:Wt. of coat, mg/cm² .31Overall metal lost,
μg/cm²/hr. .79Corrosion rate, μg/cm²/hr. .24 (100-400 hrs.)

S-49-178

CORROSION TEST RUN

Run No. 56
Date - N.B.# 832 Page 68OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>5.9</u>	Temp., °C <u>79</u>
N H ₂ O ₂ <u>1.47 x 10⁻⁴</u>	Vel., ft./sec. <u>39</u>
ppm Cl ⁻ <u>1.8</u>	Hrs. in test <u>436</u>
ppm Ca ⁺⁺ <u>0</u>	Date finished <u>8/4/43</u>
ppm SO ₄ ⁼ <u>0</u>	
ppm Mg ⁺⁺ <u>0</u>	

APPEARANCE:

Several isolated pits of 0.05 -0.1 mm depth were found. Some small oxide lumps--somewhat rough, numerous yellow-brown spots, dull.

CORROSION:Wt. of coat, mg/cm² 0.46Overall metal lost,
μg/cm²/hr. .41Corrosion rate, μg/cm²/hr. .92 ~~SECRET~~

S-49-179

CORROSION TEST RUN

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>5.7</u>	Temp., °C <u>79.9</u>
N H ₂ O ₂ <u>5.2x10⁻⁴</u>	Vel., ft./sec. <u>29½</u>
ppm Cl ⁻ <u>2.1</u>	Hrs. in test <u>438.5</u>
ppm Ca ⁺⁺ <u>0</u>	Date finished <u>8/26/43</u>
ppm SO ₄ ⁼ <u>0</u>	
ppm Mg ⁺⁺ <u>0</u>	

APPEARANCE:

Pits: Number _____
 Depth, mm _____
 Diameter at top, mm _____
 Color: _____

Numerous oxide lumps .01 mm high, .05 mm diam. on sample. Pits under oxide .02 mm deep. Oxide lumps in pits under them of approximately the same size were observed on the other two samples, but in very much smaller quantities. Surface dull light gray with general roughness.

CORROSION:

Wt. of coat, mg/cm² 0.32

Overall metal lost,
 µg/cm²/hr. 2.13

Corrosion rate, µg/cm²/hr. 1.16 (300-400 hrs.)

Run No. 58

CORROSION TEST RUN

Data - N.B.# 832 Page 98OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>5.8</u>	Temp., °C <u>69.5</u>
N H ₂ O ₂ <u>1.6 x 10⁻⁴</u>	Vel., ft./sec. <u>37.5</u>
ppm Cl ⁻ <u>3.4</u>	Hrs. in test <u>439</u>
ppm Ca ⁺⁺ <u>0</u>	Date finished <u>8/26/43</u>
ppm SO ₄ ⁻ <u>0</u>	
ppm Mg ⁺⁺ <u>0</u>	

APPEARANCE:

Pits: Number Few
Depth, mm .02
Diameter at top, mm .1

Sample had a gold tint due to very numerous very small gold-colored inclusions. Numerous small flakes and lumps of oxides .03 mm high and .1mm diam. Slightly rough.

Color:

CORROSION:Wt. of coat, mg/cm² 0.34Overall metal lost,
μg/cm²/hr. 1.14Corrosion rate, μg/cm²/hr. 1.2 (200-400 hrs.)

CORROSION TEST RUN

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>6.2</u>	Temp., °C <u>70</u>
N H ₂ O ₂ <u>4.3x10⁻⁵</u>	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>1.0</u>	Hrs. in test <u>420⁺</u>
ppm Ca ⁺⁺ <u>0</u>	Date finished <u>8/4/43</u>
ppm SO ₄ ⁻ <u>0</u>	ppm Calgon <u>3.1</u>
ppm Mg ⁺⁺ <u>0</u>	

APPEARANCE:

Somewhat rough. Numerous oxide lumps of average diameter of 0.7 mm and 0.08 mm av. height. Pits, associated with the lumps ranged in depth up to 0.2 mm and 0.3 mm diam. Av. depth 0.1 mm. Generally dull with a scattering of numerous small bright spots.

CORROSION:

Wt. of coat, mg/cm² 0.25

Overall metal lost,
μg/cm²/hr. 2.47

Corrosion rate, μg/cm²/hr. 2.4 (100-400 hrs.)

S-49-182

Run No. 60

CORROSION TEST RUN

Date - N.B.# 832 Page 67OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>6.2</u>	Temp., °C <u>70</u>
N H ₂ O ₂ <u>1.7 x 10⁻⁴</u>	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>1.05</u>	Hrs. in test <u>420</u>
ppm Ca ⁺⁺ <u>0</u>	Date finished <u>8/4/43</u>
ppm SO ₄ ⁻ <u>0</u>	ppm Calgon <u>2.6</u>
ppm Mg ⁺⁺ <u>0</u>	

APPEARANCE:

Somewhat rough, very few oxide lumps--very few edges. Average ht. of lumps equals 0.06 mm average diameter 0.2 mm. Pits associated with lumps range in depth up to 0.15 mm and 0.3 mm diam. Average depth = 0.05 mm. Very numerous, very small bright spots scattered over surface.

CORROSION:Vt. of coat, mg/cm² 0.40Overall metal lost,
μg/cm²/hr. 2.66Corrosion rate, μg/cm²/hr. 2.8 (100-400 hrs.)

S-49-183

CORROSION TEST RUN

Run No. 61Data - N.B.# 832 Page 75OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>6.1</u>	Temp., °C <u>70</u>
N H ₂ O ₂ <u>1.6 x 10⁻³</u>	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>1.0</u>	Hrs. in test <u>414</u>
ppm Ca ⁺⁺ <u>0</u>	Date finished <u>8/12/43</u>
ppm SO ₄ ⁼ <u>0</u>	ppm Calgon <u>3.4</u>
ppm Mg ⁺⁺ <u>0</u>	

APPEARANCE:

Surface approximately 50% covered with minute bright metallic spots, some larger bright spots--remainders of surface dull light gray. Some small oxide particles and larger oxide lumps. (.06 mm high, .3 mm diam.) along edges. Several pits .04 mm deep, .3 mm diam. in the oxide lumps. Somewhat rough.

CORROSION:Wt. of coat, mg/cm² 0.34Overall metal lost,
μg/cm²/hr. 3.65Corrosion rate, μg/cm²/hr. 3.65

CORROSION TEST RUN

Run No. 62Date - N.B.# 832 Page 96OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 6.1Temp., °C. 94N H₂O₂ 5.2 x 10⁻⁴Vel., ft./sec. 9ppm Cl⁻ 1.4Hrs. is test 412ppm Ca⁺⁺ 0Date finished 8-26-43ppm SO₄⁼ 0ppm Calgo. 3.0ppm Mg⁺⁺ 0APPEARANCE:Pits: Number NoneDepth, mm -----Diameter at top, mm -----

Color:

About ten brownish inclusions on one face of 2S ranging in diameter up to 0.7 mm and protruding 0.03 above surface. Moderate number oxide flakes, 0.05 mm diameter. Surface 30% covered with bright metallic spots.

CORROSION:Wt. of coat, Mg/cm² 0.28Overall metal lost, ug/cm²/hr. 5.9Corrosion rate, ug/cm²/hr. 7.1 (300-400 hrs.)

8-49-185

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.0

Temp., °C. 94

N H₂O₂ 1x10⁻⁴

Vel., ft./sec. 9

ppm Cl⁻ 2.6

Hrs. in test 461.5

ppm Ca⁺⁺

Date finished 8-30-43

ppm SO₄⁼

ppm Calgon 3.1

ppm Mg⁺⁺APPEARANCE:

Pits: Number Many
Depth, mm .04 by .08
Diameter at top, mm .01 X .05

All three samples had rough areas that looked like finger prints. One A worst, 1B least. Many oxide lumps on edges .12 X .4 mm. Pits under lump .1 mm. deep.

Color:

Dull dark gray, bright areas on ends.

CORROSION:Wt. of coat, mg/cm² 0.82Overall metal lost,
μg/cm²/hr. 7.9Corrosion rate, μg/cm²/hr. 1.4 (375-475 hrs.)
0.54 (over all)

8-49-186

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 6.1Temp., °C. 70N H₂O₂ 1.1 X 10⁻³Vel., ft/sec. 28ppm Cl⁻ 1.1Hrs. in test 418ppm Ca⁺⁺ Date finished 9-17-47ppm SO₄

ppm Calgon 3.8

ppm Mg⁺⁺ APPEARANCE:

Pits: Number none
Depth, mm
Diameter at top, mm

Moderate number minute oxide lumps.
Moderate number minute metallic
globules.

Color:

Bright, smooth surface.

CORROSION:wt. of coat, mg/cm² 0

Overall metal lost,
µg/cm²/hr. 6.5

Corrosion rate, µg/cm²/hr. 5.16

8-49-187

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>6.8</u>	Temp., °C. <u>95</u>
N H ₂ O ₂ <u>1.1 X 10⁻³</u>	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>2.5</u>	Hrs. in test <u>401.5</u>
ppm Ca ⁺⁺ <u>0</u>	Date finished <u>9-14-43</u>
ppm SO <u>4</u> <u>0</u>	ppm Calgon <u>3.7</u>
ppm Mg ⁺⁺ <u>0</u>	

APPEARANCE:

Pits: Number Several
Depth, mm _____
Diameter at top, mm _____

Several pits .1 mm X .2 mm. found on edges. Several oxide lumps .05 mm X .2 mm found on edges. Numerous minute oxide flakes on surfaces. Somewhat rough.

Color:

Samples became covered with brown coat in last 100 hrs. of run. Previously dull gray.

CORROSION:

Wt. of coat, mg/cm² .10
Corrosion rate, µg/cm²/hr. 4.45

Overall metal lost, µg/cm²/hr. 4.43

S-49-188

Run No. 66

CORROSION TEST RUN

Data - N.B.# 832 Page 125OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 6.1Temp., °C 71N H₂O₂ 1.1x10⁻⁴Vel., ft./sec. 38ppm Cl⁻ 1.3Hrs. in test 400ppm Ca⁺⁺ 0Date finished 9/14/43ppm SO₄⁻ 0ppm Calgon 3.5ppm Mg⁺⁺ 0APPEARANCE:

Samples bright and smooth, moderate number of minute oxide lumps scattered over surface. No pits.

CORROSION:Wt. of coat, mg/cm² 0.31

Overall metal lost,

μg/cm²/hr. 3.35Corrosion rate, μg/cm²/hr. 3.2

CORROSION TEST RUN

Data - N.B.# 832 Page 127OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>6.0</u>	Temp., °C <u>79</u>
N H ₂ O ₂ <u>5.9 x 10⁻⁴</u>	Vel., ft./sec. <u>15</u>
ppm Cl ⁻ <u>2.2</u>	Hrs. in test <u>393</u>
ppm Ca ⁺⁺ <u>0</u>	Date finished <u>9/16/43</u>
ppm SO ₄ ⁼ <u>0</u>	ppm NaNO ₃ <u>23.0</u>
ppm Mg ⁺⁺ <u>0</u>	ppm Calgon <u>3.1</u>

APPEARANCE:

25% of surface covered with minute, bright, metallic globules, 25% covered with minute oxide lumps. General roughness, numerous minute pits app. 0.01 mm by .03 mm. No isolate deep pits on surface or edges. Very uniform.

CORROSION:Wt. of coat, mg/cm² 0.37Overall metal lost,
μg/cm²/hr. 5.9Corrosion rate, μg/cm²/hr. 5.6

S-49-190

CORROSION TEST RUN

Run No. 68Data - N.B.# 832 Page 132OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.2 Temp., °C 68
N H₂O₂ 2.8×10^{-5} Vel., ft./sec. 9
ppm Cl⁻ 2.4 Hrs. in test 370.5
ppm Ca⁺⁺ 0 Date finished 9/16/43
ppm SO₄⁻ 0 ppm Calgon 3.3
ppm Mg⁺⁺ 0

APPEARANCE:

Pits: Number _____
Depth, mm _____
Diameter at top, mm _____

Barnacles appeared before 44 hrs.
Numerous pits .09 mm to .14 mm by .3 mm.
Numerous oxide lumps .18 mm to .04 mm x .04mm.
Oxide lumps on edges .7 mm diam. Moderately
rough, 50% covered with small oxide flakes.

Color:

CORROSION:

Wt. of coat, mg/cm² 1.44
Corrosion rate, µg/cm²/hr. 3.0

Overall metal lost,
µg/cm²/hr. 6.77

S-49-191

CORROSION TEST RUN

Data - N.B.# 832 Page 133

Object:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 7.4 by corrosion lab.
7.1 by analytical lab.

Temp., °C 70

N H₂O₂ 1.1x10⁻⁴

Vel., ft./sec. 15

ppm Cl⁻ 2.4

Hrs. in test 413.5

ppm Ca⁺⁺ 0

Date finished 9/21/45

ppm SO₄⁻² 0

ppm Calgon 3.5

APPEARANCE:ppm PO₄ .4Pits: Number _____
Depth, mm _____
Diameter at top, mm _____

Few small barnacles appeared before 135 hrs. Moderate number at end of run up to .06x.3 mm. Moderate number pits .06 mm x .1 mm. Edges no worse than surfaces. Surface approx. 50% covered with minute oxide flakes. Moderately rough.

Color:

CORROSION:Wt. of coat, mg/cm² 0.43Overall metal lost,
µg/cm²/hr. 3.59Corrosion rate, µg/cm²/hr. 1.95

8-49-192

CORROSION TEST RUN

Run No. 70Data - N.B.# 832 Page 151OBJECT:

To determine the corrosion of alclad aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

N H ₂ O ₂ <u>1.4x10⁻⁴</u>	Temp., °C <u>95</u>
pH <u>6.5</u>	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>2.5</u>	Hrs. in test <u>401</u>
ppm Ca ⁺⁺ <u>0</u>	Date finished <u>10/1/43</u>
ppm SO ₄ ⁼ <u>0</u>	
ppm Mg ⁺⁺ <u>0</u>	

APPEARANCE:

Pits: Number _____
Depth, mm _____
Diameter at top, mm _____

Moderate number of pits .01 mm x .03 mm, mostly with bro.n colored craters. Very few pits .1 mm x .15 mm. Surface smooth and dull, very few oxide lumps, numerous pits on edges of the same size as on surface.

Color:

CORROSION:Wt. of coat, mg/cm² .23Overall metal lost,
μg/cm²/hr. .65Corrosion rate, μg/cm²/hr. .11(0-200 hrs.)
.28(300-400 hrs.)

SECRET

S-49-193

OBJECT:

To determine the corrosion of alclad (72S-3S) aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH	6.4	Temp., °C	70
N H ₂ O ₂	1.6x10 ⁻⁴	Vel., ft./sec.	9
ppm Cl ⁻	2.3	Hrs. in test	378.5
ppm Ca ⁺⁺	0	Date finished	10/2/45
ppm SO ₄ ⁼	0		
ppm Mg ⁺⁺	0		

APPEARANCE:

Pits: Number Moderate Pitting on edges, somewhat less than surfaces.
Depth, mm .1
Diameter at top, mm .45
Color: Surface rough with noncontinuous tan coat.

CORROSION:

Wt. of coat, mg/cm ²	<u>.67</u>	Overall metal lost,	
Corrosion rate, µg/cm ² /hr.	<u>1.15</u>	µg/cm ² /hr.	<u>2.67</u>

S-49-194

CORROSION TEST RUN

Run No. 72Data - N.B.# 832 Page 152OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.2 Temp., °C 68
N H₂O₂ 1.2x10⁻⁵ Vel., ft./sec. 38
ppm Cl⁻ 1.2 Hrs. in test 406.5
ppm Ca⁺⁺ 0 Date finished 10/2/43
ppm SO₄⁻ 0 ppm Calgon 4.0
ppm Mg⁺⁺ 0

APPEARANCE:

Pits: Number None Surface approx. 10% covered with minute
Depth, mm bright metallic globules .005 mm diam. Small
Diameter at top, mm no. oxide lumps .01 mm diam. Smooth
Color: surface.

CORROSION:Wt. of coat, mg/cm² 0.25Overall metal lost,
μg/cm²/hr. 5.05Corrosion rate, μg/cm²/hr. 5.0

S-49-195

CORROSION TEST RJA

Run No. 73

Data - N.B.# 832 Page 150

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH	6.3	Temp., °C	70
N H ₂ O ₂	9.9×10^{-4}	Vel., ft./sec.	28
ppm Cl ⁻	2.0	Hrs., in test	400
ppm Ca ⁺⁺	0	Date finished	9/30/43
ppm SO ₄ ⁼	0	ppm Calgon	4.0
ppm Mg ⁺⁺	0		

APPEARANCE:

Pits: Number None
Depth, mm
Diameter at top, mm

Slightly rough about 25% covered with
minute bright metallic globules. Small
oxide flakes.

Color:

CORROSION:

Wt of coat, mg/cm² 0.20
Corrosion rate, µg/cm²/hr. 6.1

Overall metal lost,
µg/cm²/hr. 6.5

S-49-196

OBJECT:

To determine the corrosion of 2S aluminum in actual river water at the following conditions.

CONDITIONS: (Average thruout run)

pH 8.1 Temp., °C 80
 N H₂O₂ 1.1x10⁻⁴ Vel., ft./sec. 15
 ppm Cl⁻ 1.1 Hrs. in test 438
 ppm Ca⁺⁺ _____ Date finished 10/8/43
 ppm SO₄⁼ _____
 ppm Mg⁺⁺ _____

APPEARANCE:

Site: Number Numerous Surface 90% covered with .03mm
 Depth, mm 0.1 to .3 thick layer of small dark oxide
 Diameter at top, mm 0.15 to 1.0 crystals. This layer is 50%
 Color: Covered with a network of oxide
 Black coat of oxide layer in 50 hrs. lumps .16 mm high.

CORROSION:

Wt. of coat, mg/cm² 3.1 Overall metal lost,
 μg/cm²/hr. 53.2
 Corrosion rate, μg/cm²/hr. 57.2 (0-175 hrs.)
29.8 (175-450 hrs.)

CORROSION TEST RUN

OBJECT:

To determine the corrosion of 2S and alclad (72S-3S) aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>7.4</u>	Temp., °C <u>70</u>
N H ₂ O ₂ <u>1.3x10⁻⁴</u>	Vel., ft./sec. <u>15</u>
ppm Cl ⁻ <u>1.4</u>	Hrs. in test <u>429.</u>
ppm Ca ⁺⁺ <u>0</u>	Date finished <u>10/11/43</u>
ppm SO ₄ ²⁻ <u>0</u>	ppm Calgon <u>3.5</u>
ppm Mg ⁺⁺ <u>0</u>	ppm PO ₄ <u>.6</u>

APPEARANCE:

Pits: Number _____
 Depth, mm _____
 Diameter at top, mm _____

Color:

Brown coat on all
 samples by 140 hrs.

CORROSION:

Wt. of coat, mg/cm² 2S=.88 Alclad .86

Corrosion rate, µg/cm²/hr. 2S=4.45
Alclad = 5.03

2S Al
 Oxide coat .005 mm thick covering 80% of
 surface causing general roughness. No pits.

Alclad
 Moderate no. elongated pits .01 mm deep, .07 mm
 wide, .03 mm long. General roughness given by
 bright metallic luster of pits. Few normal pits
 .03x.15 mm. Few brown inclusions .7 mm diam.
 Remainder of surface covered with fine grain oxide
 coat .001 mm thick.

Overall metal lost,
 µg/cm²/hr. 6.45 = 2S
6.84 = Alclad

S-49-198

CORROSION TEST RUN

Run No. 76Data - N.B.# 832 Page 182OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>7.2</u>	Temp., °C. <u>70</u>
N H ₂ O ₂ <u>2.3 x 10⁻⁴</u>	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>1.1</u>	Hrs. in test <u>401</u>
ppm Ca ⁺⁺ <u>2.4</u>	Date finished <u>10/22/43</u>
ppm SO ₄ ⁼ <u>74.0</u>	
ppm Mg ⁺⁺ <u>2.1</u>	

APPEARANCE:

Pits: Number Ions
 Depth, mm
 Diameter at top, mm
 Color:

Approximately 95% of surface covered with yellow coating .001 to .01 mm thick. Surface generally rough due to combination of these very shallow pits with the coating. (Visible by microscope only). No large isolated pits or lumps of oxide.

CORROSION:

Wt. of coat, mg/cm² 1.73
 Corrosion rate, µg/cm²/hr. 1.55

Overall metal lost,
 µg/cm²/hr. 5.46

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 7.5Temp., °C. 95N H₂O₂ 1.4 x 10⁻⁴Vel., ft./sec. 9ppm Cl⁻ 1.5Hrs. in test 401ppm Ca⁺⁺ 3.2Date finished 10-22-43ppm SO₄⁼ 74.0ppm Mg⁺⁺ 2.3APPEARANCE:Pits: Number NoneDepth, mm Diameter at top, mm

Color: Light tan. Pits in coat combine to give surface appearance of general roughness. Surface slightly rougher at ends where coat was worn away. No isolated large pits or large oxide lumps.

CORROSION:Wt. of coat, mg/cm² 4.42Overall metal lost,
μg/cm²/hr. 15.8Corrosion rate, μg/cm²/hr. 4.25

SECRET

S-49-200

~~SECRET~~

-202-

Run No. 78

CORROSION TEST RUN

Data - N.B.//832 Page 184OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 7.2Temp., °C. 80N H₂O₂ 1.4 x 10⁻⁴Vel., ft./sec. 38ppm Cl⁻ 1.2Hrs. in test 403.5ppm Ca⁺⁺ 2.8Date finished 10/22/43ppm SO₄⁻ 70ppm Mg⁺⁺ 2.1APPEARANCE:Pits: Number NoneDepth, mm Diameter at top, mm Color: Moderate roughness.CORROSION:Wt. of coat, mg/cm² 0.50

Overall metal lost,

μg/cm²/hr. 0.76Corrosion rate, μg/cm²/hr. Sample showing no wear on holder tits. 0.462.0 (Average of 3 samples) ~~SECRET~~

8-49-201

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>7.1</u>	Temp., °C. <u>80</u>
N H ₂ O ₂ <u>1.2 x 10⁻⁵</u>	Vel., ft./sec. <u>28</u>
ppm Cl ⁻ <u>1.2</u>	Hrs. in test <u>404.5</u>
ppm Ca ⁺⁺ <u>2.3</u>	Date finished <u>10/22/43</u>
ppm SO ₄ ⁼ <u>73</u>	
ppm Mg ⁺⁺ <u>2.0</u>	

APPEARANCE:

Pits: Number None
 Depth, mm
 Diameter at top, mm
 Color: Medium grey
 Roughened surface

CORROSION:

Wt. of coat, mg/cm² .66 Overall metal lost, 5.68 µg/cm²/hr.
 Corrosion rate, µg/cm²/hr. 1.9 (Sample showing no wear on holder ends)
7.6 (Average of 3 samples)

CORROSION TEST RUN

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 7.3

Temp., °C. 70

N H₂O₂ 2.7×10^{-4}

Vel., ft./sec. 9

ppm Cl⁻ 1.0

Hrs. in test 410.

ppm Ca⁺⁺ 27.0

Date finished 11/9/43

ppm SO₄⁻ 66.0ppm Mg⁺⁺ 7.0APPEARANCE:

Coat .01 mm thick, slight roughness
due to very numerous cracks in coat.

Pits: Number None

No large isolated pits found upon
removal of coat. Mild corrosion. Coat
very adherent.

Depth, mm

Diameter at top, mm

Color:

CORROSION:Wt. of coat, mg/cm² 0.4

Overall metal lost,
μg/cm²/hr. 3.80

Corrosion rate, μg/cm²/hr. 3.0

CORROSION TEST RUN

Data - N.B.# 54B Page 12

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: - (Average thruout run)

pH	7.3	Temp., °C.	80
N H ₂ O ₂	6.0x10 ⁻⁴	Vel., ft./sec.	38
ppm Cl ⁻	1.2	Hrs. in test	410.
ppm Ca ⁺⁺	21.0	Date finished	11/9/43
ppm SO ₄ ⁼⁼	63		
ppm Mg ⁺⁺	6.7		

APPEARANCE:Pits: Number None

Depth, mm

Diameter at top, mm

Color:

Dark rough oxide coat .01 mm thick--when scraped off, no large isolated pits were discovered. Coat very adherent. Several pits .5 mm deep and .9 mm diam. were found on the ends. These are probably erosion pits due to the manner in which the water flowed over the sample holders. Two of the samples showed a visible am't. of end wear due to the sample holders.

CORROSION:Wt. of coat, mg/cm² 4.6Overall metal lost,
µg/cm²/hr. 17.7Corrosion rate, µg/cm²/hr. 4.68 - 1 sample8.15 - Av. of 3 samples

CORROSION TEST : UN

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH	7.3	Temp., °C.	80
N H ₂ O ₂	4.7×10^{-6}	Vel., ft./sec.	23
ppm Cl ⁻	1.0	Hrs. in test	410.
ppm Ca ⁺⁺	23.0	Date finished	11/9/43
ppm SO ₄ ⁼	77.0		
ppm Mg ⁺⁺	6.2		

APPEARANCE:Pits: Number None

Depth, mm _____

Diameter at top, mm _____

Color: _____

Very adherent rough coat .01 mm thick--no large isolated pits were found when portion of coat was removed. Ends of two of the samples were very badly worn by the sample holders. Very numerous trenches or elongated pits .001 mm deep and .01 mm wide X .07 mm -.10 mm long. Much general roughness.

CORROSION:Wt. of coat, mg/cm² 3.4Overall metal lost, 14.3 $\mu\text{g}/\text{cm}^2/\text{hr.}$ Corrosion rate, $\mu\text{g}/\text{cm}^2/\text{hr.}$ 6.2 (1 sample)
14.6 (3 samples)

OBJECT:

To determine the corrosion of alclad (72S-3S) aluminum at the following conditions:
CONDITIONS: = (Average thruout run)

pH 7.3 Temp., °C. 70
N H₂O₂ 1.8 X 10⁻⁴ Vel., ft./sec. 9
ppm Cl⁻ 1.2 Hrs. in test 417.
ppm Ca⁺⁺ 2.9 Date finished 11-4-43
ppm SO₄⁻² 85
ppm Mg⁺⁺ 2.5

APPEARANCE:

Pits: Number None
Depth, mm
Diameter at top, mm

Color: 50% surface covered with bright metallic globules .01mm. diameter.
Walls of pits are bright and steep. Bottoms dull and flat. Apparently
penetrating the clad but not entering the base metals.

CORROSION:

Wt. of coat, mg/cm² 0.15

Overall metal lost,
μg/cm²/hr. 2.05

Corrosion rate, μg/cm²/hr. 1.64

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions and alclad (72S-3S) aluminum;

CONDITIONS: -(Average thruout run)

pH 7.8

Temp., °C 69

N H₂O 1.6x10⁻³

Vel., ft./sec. 15

ppm Cl⁻ 1.0

Hrs. in test 421.25

ppm Ca⁺⁺ 0

Date finished 11/6/43

ppm SO₄⁼ 0

ppm Calgon ⁼ 3.1

ppm Mg⁺⁺ 0

ppm PO₄⁼ .4

APPEARANCE:

Pits: Number

Depth, mm

Diameter at top, mm

Color:

2S aluminum--Oxide coat .001 mm-.005 mm thick, no large isolated pits found upon coat removal, mild corrosion, very adherent coat. Alclad--same as 2S aluminum.

CORROSION:

Wt. of coat, mg/cm² 2S 1.94

Overall metal lost,

μg/cm²/hr. 2S 3.16

Corrosion rate, μg/cm²/hr. 1.95 (200-400 hrs.) Alclad

Alclad 3.35

S-49-207

CORROSION TEST RUN

Run No. 85Data - N.B. # 54B Page 28OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>6.5</u>	Temp., °C <u>95</u>
N H ₂ O ₂ <u>2.1x10⁻⁴</u>	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>1.4</u>	Hrs. in test <u>406</u>
ppm Ca ⁺⁺ <u>26.1</u>	Date finished <u>11/20/43</u>
ppm SO ₄ ⁼ <u>102.0</u>	
ppm Mg ⁺⁺ <u>10.7</u>	

APPEARANCE:

Pits: Number None Very adherent coat .001-.005 mm thick-
 Depth, mm moderately rough. Removal of coat on
 Diameter at top, mm sample 3B by method of p10 disclosed very
 Color: numerous pits.
 Bright walls-general mild corrosion.

CORROSION:

Wt. of coat, mg/cm² 2.4 Overall metal lost,
 µg/cm²/hr. 8.5
 Corrosion rate, µg/cm²/hr. 5.04 (150-250 hrs.)
.16 (300-400 hrs.)

S-49-208

CORROSION TEST RUN

Run No. 86Data - N.B.# 54B Page 29OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 4.5 Temp., °C 94
N H₂O₂ 3.1x10⁻⁴ Vel., ft./sec. 9
ppm Cl⁻ 1.2 Hrs. in test 404
ppm Ca⁺⁺ 21.1 Date finished 11/22/43
ppm SO₄⁼ 100.9
ppm Mg⁺⁺ 9.3

APPEARANCE:

Pits: Number None Bright walled trenches .001mm deep and
Depth, mm .02 mm wide the entire length of the
Diameter at top, mm Sample. General mild Corrosion.
Color: Tan coloration

CORROSION:

Wt. of coat, mg/cm² 0.46 Overall metal lost,
Corrosion rate, µg/cm²/hr. .85(150-400 hrs.) µg/cm²/hr. 2.35

S-49-209

CORROSION TEST RUN

Run No. 37

Data - N.B.# 54B Page 44

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 3.9

Temp., °C 68

N H₂O₂ 1.1×10^{-4}

Vel., ft./sec. 9

ppm Cl⁻ .9

Hrs. in test 396

ppm Ca⁺⁺ 14.2

Date finished 11/30/43

ppm SO₄⁼ 48.8ppm Mg⁺⁺ 6.2APPEARANCE:

Pits: Number No large isolated pits.
Depth, mm _____
Diameter at top, mm _____

Color:

Sample 1B was treated with nitric acid to remove the coat and the wt. loss was .086 mg/cm² or an overall rate of wt. change for the entire run (based on this uncoated sample) of -8.7 mg/cm²/hr. Coat consisted of a deposit of flakes covering 50% of the surface. Surface generally rough. The uncoated sample disclosed no further information.

CORROSION:Wt. of coat, mg/cm² 0.09Overall metal lost,
μg/cm²/hr. 8.6Corrosion rate, μg/cm²/hr. 8.4

S-49-210

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH	4.0	Temp., °C	94
N H ₂ O ₂	1.2 x 10 ⁻⁴	Vel., ft./sec.	9
ppm Cl ⁻	1.1	Hrs. in test	400
ppm Ca ⁺⁺	16.9	Date finished	11-29-43
ppm SO ₄ ⁻	74.0		
ppm Mg ⁺⁺	8.9		

APPEARANCE:

Pits: Number Few
 Depth, mm .02
 Diameter at top, mm Few:

Color: Brown color developed after 350 hrs.

Sample 2C was uncoated after being treated by the nitric acid method and it lost .408 mg/cm² in the process. Overall rate of wt. change (based on this uncoated sample) was -3.56/mg/cm²/hr. Some pitting on edges and around sample support hook holes after 125 hrs. Coat .001-.005 mm thick.

CORROSION:

Wt. of coat, mg/cm² 0.41

Overall metal lost, 3.4 µg/cm²/hr.

Corrosion rate, µg/cm²/hr. 4.0 (0-100 hrs.)
.29 (300-400 hrs.)

S-49-211

CORROSION TEST RUN

Run No. 89Data - N.B.# 54B Page 45OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 4.0Temp., °C 91N H₂O 23x 10⁻⁴Vel., ft./sec. 20ppm Cl⁻ 1.0Hrs. in test 397 $\frac{1}{2}$ ppm Ca⁺⁺ 15.5Date finished 11/30/43ppm SO₄⁻ 45.4ppm Mg⁺⁺ 5.5APPEARANCE:Pits: Number ModerateDepth, mm 0.5-1.0Diameter at top, mm 2-4

Color:

CORROSION:Wt. of coat, mg/cm² 0.8Overall metal lost,
µg/cm²/hr. 31Corrosion rate, µg/cm²/hr. 31.9 ~~SECRET~~

S-49-212

Run No. 90

CORROSION TEST RUN

Data - N.B.# 54B Page 46OBJECT:

To determine the corrosion of 1S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 3.2 Temp., °C 93
 N H₂O₂ 1.4x10⁻⁴ Vel., ft./sec. 9
 ppm Cl⁻ 1.1 Hrs. in test 396
 ppm Ca⁺⁺ 21.2 Date finished 11-30-43
 ppm SO₄⁼ 115.4
 ppm Mg⁺⁺ 6.8

APPEARANCE:

Pits: Number Numerous
 Depth, mm 0.1-0.25
 Diameter at top, mm 0.5-1.0
 Color:
 Gray coat on unpitted surface.

CORROSION:

Wt. of coat, mg/cm² 4.2 Overall metal lost,
 µg/cm²/hr. 129
 Corrosion rate, µg/cm²/hr. 173(200-400 hrs.)
120(overall)

S-49-213

CORROSION TEST RUN

Run No. 91Data N.B.# 54-B Page 51OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 4.7Temp., °C 93N H₂O₂ 4.0x10⁻⁴Vel., ft./sec. 29ppm Cl⁻ 0.9Hrs. in test 414ppm Ca⁺⁺ 11.9Date finished 12-3-43ppm SO₄⁼ 46.2ppm Mg⁺⁺ 5.2APPEARANCE:Pits; Number NoneDepth, mm Diameter at top, mm

Color:

Roughened surface.

CORROSION:Wt. of coat, mg/cm² 0.37Overall metal lost,
μg/cm²/hr. 1.55Corrosion rate, μg/cm²/hr. 0.33(100-400 hrs.)
2.3(0-67 Hrs.)

CORROSION TEST RUN

Run No. 92

Data - N.B.# 54-B Page 72

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 5.4

Temp., °C 93

N H₂O 1.1x10⁻⁴

Vel., ft./sec. 21

ppm Cl⁻ 1.2

Hrs. in test 411½

ppm Ca⁺⁺ 6.6

Date finished 12-11-43

ppm SO₄⁻ 54.7

ppm Mg⁺⁺ 5.1

APPEARANCE:

Pits: Number None
Depth, mm
Diameter at top, mm

Color:

Moderate roughness

CORROSION:

Wt. of coat, mg/cm² 0

Overall metal lost,
µg/cm²/hr. 1.9

Corrosion rate, µg/cm²/hr. .96 (0-200 hrs.)
0.28 (200-400 hrs.)

S-49-215

CORROSION TEST RUN

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average throughout run)Temp., °C 71pH 5.3Vel., ft./sec. 9N H₂O₂ 1.5×10^{-4} Hrs. in test 410 $\frac{1}{2}$ ppm Cl⁻ 1.9Date finished 12-21-43ppm Ca⁺⁺ 11.0ppm SO₄⁼ 77ppm Mg⁺⁺ 8APPEARANCE:

Pits: Number None
Depth, mm _____
Diameter at top, mm _____

Color: Dark, dull gray. Smooth surface.

CORROSION:Wt. of coat, mg/cm² .34Overall metal lost,
µg/cm²/hr. .93Corrosion rate, µg/cm²/hr 0.2

L-49-216

CORROSION TEST RUN

Run No. 94

Data - N.B.# 54-B Page 88

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITION: - (Average thruout run)

pH <u>5.4</u>	Temp., °C <u>95</u>
N H ₂ O ₂ <u>1.2x10⁻⁴</u>	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>1.4</u>	Hrs. in test <u>415</u>
ppm Ca ⁺⁺ <u>13</u>	Date finished <u>12/21/43</u>
ppm SO ₄ ⁻ <u>80</u>	
ppm Mg ⁺⁺ <u>7</u>	

APPEARANCE:

Fits: Number Several

Depth, mm 0.1
Diameter at top, mm 2.0

Color:

Orange discoloration Moderate general roughness

CORROSION:

Wt. of coat, mg/cm² .57

Overall metal lost,
µg/cm²/hr. 1.45

Corrosion rate, µg/cm²/hr. .15(0-400 hrs.)

~~SECRET~~

-219-

Run No. 95

CORROSION TEST RUN

Date - N.B.# 54-B Page 89

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>5.7</u>	Temp., °C <u>93</u>
N H ₂ O ₂ <u>2.5x10⁻⁴</u>	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>1.6</u>	Hrs. in test <u>409</u>
ppm Ca ⁺⁺ <u>17</u>	Date finished <u>12-22-43</u>
ppm SO ₄ ⁻ <u>117</u>	
ppm Mg ⁺⁺ <u>12</u>	

APPEARANCE:

Pits: Number Several
Depth, mm 0.4-0.6
Diameter at top, mm 0.5-1.5
Color:

CORROSION:

Wt. of coat, mg/cm² .84
Corrosion rate, $\mu\text{g/cm}^2/\text{hr.}$.28(0-75 hrs.)
.6(100-400 hrs.)

Overall metal lost,
 $\mu\text{g/cm}^2/\text{hr.}$ 2.49

~~SECRET~~

S-49-218

CORROSION TEST RUN

Run No. 96

Data - N.B.# 54-B Page 90

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: (Average thruout run)

pH <u>5.4</u>	Temp., °C <u>94</u>
N H ₂ O ₂ <u>1.3x10⁻⁴</u>	Vel., ft./sec. <u>23</u>
ppm Cl ⁻ <u>1.1</u>	Hrs. in test <u>400½</u>
ppm Ca ⁺⁺ <u>11</u>	Date finished <u>12/21/43</u>
ppm SO ₄ ⁼ <u>81</u>	
ppm Mg <u>6</u>	

APPEARANCE:

Pits: Number Several
 Depth, mm .02
 Diameter at top, mm .15
 Color:
 Light grey.

CORROSION:

Wt. of coat, mg/cm ² <u>0</u>	Overall metal lost, µg/cm ² /hr. <u>0</u>
Corrosion rate, µg/cm ² /hr. <u>1</u>

CORROSION TEST RUN

Run No 97Data - N.B.# 54-BPage 91OBJECT:To determine the corrosion of ~~2S~~ aluminum at the following conditions:CONDITIONS:-(Average thruout run)pH 5.2Temp., °C 93N H₂O₂ 1.3x10⁻⁴Vel., ft./sec. 20ppm Cl⁻ 1.2Hrs. in test 402ppm Ca⁺⁺ 9Date finished 12-20-43ppm SO₄⁻ 79ppm Mg⁺⁺ 6APPEARANCE:Pits: Number ModerateDepth, mm .08-.1Diameter at top, mm .4-.6

Color:

Dark grey.

CORROSION:Wt. or coat, mg/cm² .54Overall metal lost,
μg/cm²/hr. 2.5Corrosion rate, μg/cm²/hr. .91 (100-400 hrs.) ~~SECRET~~

L-49-220

~~SECRET~~
-222-
CORROSION TEST RUN

Run No. 98

Data - N.B.# 54-B Page 91

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>3.4</u>	Temp., °C <u>70</u>
N H ₂ O ₂ <u>1.0x10⁻⁴</u>	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>1.3</u>	Hrs. in test <u>404¹</u>
ppm Ca ⁺⁺ <u>11</u>	Date finished <u>12- 21-43</u>
ppm SO ₄ ⁼ <u>169</u>	
ppm Mg ⁺⁺ <u>7</u>	

APPEARANCE:

Pits: Number Moderate
 Depth, mm 1-.2
 Diameter at top, mm 3- .5

Color: Clean. Roughened surface, seriously corroded.

CORROSION:

Wt. of coat, mg/cm² 0

Overall metal lost,
 µg/cm²/hr. 156

Corrosion rate, µg/cm²/hr. 170 (100-400 hrs.)

TIME (hours) ~~SECRET~~

S-49-221

CORROSION TEST RUN

Run No. 99

Date - N.B.# 54-B Page 93

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>5.8</u>	Temp., °C <u>70</u>
N H ₂ O ₂ <u>3.6x10⁻⁴</u>	Vel., ft./sec. <u>15</u>
ppm Cl ⁻ <u>1.2</u>	Hrs. in test <u>401$\frac{1}{2}$</u>
ppm Ca ⁺⁺ <u>12.0</u>	Date finished <u>12/22/43</u>
ppm SO ₄ ⁼ <u>88</u>	
ppm Mg ⁺⁺ <u>7</u>	

APPEARANCE:

Pits: Number None
Depth, mm
Diameter at top, mm

Color: Moderate roughness.
Dull grey.

CORROSION:

Wt. of coat, mg/cm ² <u>.32</u>	Overall metal lost, <u> </u>
Corrosion rate, ug/cm ² /hr. <u>.07 (0-400 hrs.)</u>	ug/cm ² /hr. <u>.87</u>

CORROSION TEST RUN

Run No. 100Data - N.B. # 54-B Page 122OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 4.4 Temp., °C 70
N H₂O₂ 1.2x10⁻⁴ Vel., ft./sec. 9
ppm Cl⁻ 1.2 Hrs. in test 423
ppm Ca⁺⁺ 23 Date finished 1/10/44
ppm SO₄⁻ 112
ppm Mg⁺⁺ 5

APPEARANCE:

Pits: Number None
Depth, mm
Diameter at top, mm

Color:

Light grey coat. Mild general roughness.

CORROSION:Wt. of coat, mg/cm² .12Overall metal lost,
μg/cm²/hr. 0.87Corrosion rate, μg/cm²/hr. .83 (100-400 hrs.)

S-49-223

CORROSION TEST RUN

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 4.8Temp., °C 93N H₂O 1x10⁻⁴Vel., ft./sec. 9ppm Cl⁻ 1.5Hrs. in test 423ppm Ca⁺⁺ 23Date finished 1/10/44ppm SO₄⁼ 150ppm Mg⁺⁺ 8APPEARANCE:Pits: Number ManyDepth, mm .05-.1Diameter at top, mm .1-.2

Color:

Medium dark gray coat. Mild general roughness.

CORROSION:Wt. of coat, mg/cm² .51Overall metal lost,
μg/cm²/hr. 3.0Corrosion rate, μg/cm²/hr. 1.1

CORROSION TEST RUN

Run No. 102

Data - N.B.# 54-B Page 124

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>4.9</u>	Temp., °C. <u>93</u>
N H ₂ O ₂ <u>.4</u> x 10 ⁻⁴	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>1.5</u>	Hrs. in test <u>402</u>
ppm Ca ⁺⁺ <u>31</u>	Date finished <u>1/10/44</u>
ppm SO ₄ ⁻ <u>158</u>	
ppm Mg ⁺⁺ <u>8</u>	

APPEARANCE:

Pits: Number None
 Depth, mm
 Diameter at top, mm

Color: Bright, medium dark gray coat. Moderate general roughness.

CORROSION:

Wt. of coat, mg/cm ² <u>1.05</u>	Overall metal lost, <u> </u>
Corrosion rate, µg/cm ² /hr. <u>.28 (0-400 hrs.)</u>	µg/cm ² /hr. <u>3.57</u>

CORROSION TEST RUN

Run No. 103

Data - N.B.# 54-B Page 125

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>5.0</u>	Temp., °C. <u>94</u>
NH ₂ O ₂ <u>2x10⁻⁶*</u>	Vel., ft./sec. <u>23</u>
ppm Cl ⁻ <u>1.2</u>	Hrs. in test <u>423</u>
ppm Ca ⁺⁺ <u>19</u>	Date finished. <u>1/10/44</u>
ppm SO ₄ ⁻ <u>84</u>	
ppm Mg ⁺⁺ <u>2.0</u>	

APPEARANCE:

Pits: Number None
 Depth, mm
 Diameter at top, mm

Color:

Dark gray coat. Moderate general roughness

CORROSION:

Wt. of coat, mg/cm ² <u>.30</u>	Overall metal lost, <u> </u>
Corrosion rate, µg/cm ² /hr. <u>.39 (100-425 hrs.)</u>	µg/cm ² /hr. <u>1.01</u>
	<u>.16 (0-100 hrs.)</u>

CORROSION TEST RUN

OBJECT:

To determine the corrosion of 72S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>5.0</u>	Temp., °C. <u>73</u>
N H ₂ O ₂ <u>1.4 x 10⁻⁴</u>	Vel., ft./sec. <u>20</u>
ppm Cl ⁻ <u>1.1</u>	Hrs. in test <u>399</u>
ppm Ca ⁺⁺ <u>22.4</u>	Date finished <u>1/1/44</u>
ppm SO ₄ ⁻ <u>87.8</u>	
ppm Mg ⁺⁺ <u>6.3</u>	

APPEARANCE:

Pits: Number Moderate
 Depth, mm .05-.1
 Diameter at top, mm .2

Color:

Light grey coat. Moderate general roughness.

CORROSION:

Wt. of coat, mg/cm² .012

Overall metal lost,
 µg/cm²/hr. 1.08

Corrosion rate, µg/cm²/hr. .3(0-165 hrs.)
2.05(165-400 hrs.)

Run No. 105

CORROSION TEST RUN

Data - N.B.# 54-B Page 126OBJECT:

To determine the corrosion of 72S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.0 Temp., °C. 92
N H₂O₂ 2 x 10⁻⁵ Vel., ft./sec. 23
ppm Cl⁻ 1.2 Hrs. in test 398
ppm Ca⁺⁺ 22 Date finished 1/8/44
ppm SO₄⁻ 79
ppm Mg⁺⁺ 3

APPEARANCE:

Pits: Number Few
Depth, mm .02
Diameter at top, mm .09

Color:
Very dark gray coat.

CORROSION:Wt. of coat, mg/cm² 1.70Overall metal lost,
μg/cm²/hr. 6.1Corrosion rate, μg/cm²/hr. .8 (0-200 hrs.)
3.7 (200-400 hrs.)

CORROSION TEST RUN

Run No. 106Data -N.B.# 54-B Page 127OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 8.3Temp., °C. 78N H₂O₂ 2 x 10⁻⁴Vel., ft./sec. 15ppm Cl⁻ 1.1Hrs. in test 402ppm Ca⁺⁺ 27Date finished 1/10/44ppm SO₄⁻ 126

1 ppm Calgon

ppm Mg⁺⁺ 4APPEARANCE:

Pits: Number	<u>Few</u>	Many
Depth, mm	<u>.04</u>	<u>.1</u>
Diameter at top, mm	<u>0.2</u>	<u>.2</u>

Color:

Medium gray

CORROSION:Wt. of coat, mg/cm² 2.97Overall metal lost,
μg/cm²/hr. 17.3Corrosion rate, μg/cm²/hr. 12(0-400 hrs.)

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 8.4

Temp., °C. 79

N H₂O₂ .44 x 10⁻⁴

Vel., ft./sec. 15

ppm Cl⁻ 1.2

Hrs. in test 402

ppm Ca⁺⁺ 18

Date finished 1/10/44

ppm SO₄⁻² 111ppm Mg⁺⁺ 4APPEARANCE:

Pits: Number On edges and in holes

Depth, mm .55

Diameter at top, mm .05-.1

Color:

Gray coat.

CORROSION:Wt. of coat, mg/cm² 3.04Overall metal lost,
μg/cm²/hr. 8.8Corrosion rate, μg/cm²/hr. .33 (0-300 hrs.)
4 (300-400 hrs.)

S-49-230

CORROSION TEST RUN

Run NO. 108

Data - N.B.# 54B Page 162

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.1

Temp., °C. 70

N H₂O₂ 1.2 x 10⁻⁴

Vel., ft./sec. 9

ppm Cl⁻ 1.2

Hrs. in test 386

ppm Ca⁺⁺ 22

Date finished 1-29-44

ppm SO₄⁻ 107

ppm Mg⁺⁺ 3.4

APPEARANCE:

Pits: Number None

Depth, mm

Diameter at top, mm

Color:

Grey dull coat. Smooth

CORROSION:

Wt. of coat, mg/cm² .39

Overall metal lost,
µg/cm²/hr. 1.28

Corrosion rate, µg/cm²/hr. .39(120-386 hrs.)

CORROSION TEST RUN

Run No. 109

Data - N.B.# 54B Page 163

OBJECT:

To (increase) corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.5

Temp., °C. 94

N H₂O₂ 0.8 x 10⁻⁴

Vel., ft./sec. 9

ppm Cl⁻ 1.2

Hrs. in test 401½

ppm Ca⁺⁺ 23

Date finished 1-31-44

ppm SO₄⁻ 116

ppm Mg⁺⁺ 3.7

APPEARANCE:

Pits: Number Few on edge.

Depth, mm .1

Diameter at top, mm .75

Color:

Grey, dull.

CORROSION:

Wt. of coat, mg/cm² 0.65

Overall metal lost,
µg/cm²/hr. 2.2

Corrosion rate, µg/cm²/hr. 1.1(0-100 hrs.)

0.5(100-400 hrs.)

CORROSION TEST RUN

Run No. 110

Data - N.B.# 54B Page 164

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.7

Temp., °C. 94

N H₂O₂ .8 x 10⁻⁴

Vel., ft./sec. 9

ppm Cl⁻ 1.2

Hrs. in the test 401½

ppm Ca⁺⁺ 23

Date finished 1-31-44

ppm SO₄⁻ 121ppm Mg⁺⁺ 4.2APPEARANCE:

Pits; Number None

Depth, mm

Diameter at top, mm

Color:

Light tan coat. Smooth surface.

CORROSION:Wt. of coat, mg/cm² 1.06Overall metal lost,
μg/cm²/hr. 3.22Corrosion rate, μg/cm²/hr. 1.76 (0-100 hrs.)
0.10 (150-400 hrs.)

S-49-233

CORROSION TEST RUN

Run No. 111

Data - N.B.# 54B Page 145

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.0

Temp., °C. 80

N H₂O₂ 1 x 10⁻³

Vel., ft./sec. 25

ppm Cl⁻ 1.4

Hrs. in test 404

ppm Ca⁺⁺ 24

Date finished 1-29-44

ppm SO₄⁻ 96

ppm Mg⁺⁺ 3.1

APPEARANCE:

Pits: Number Few:

Depth, mm .05 -.1;

Diameter at top, mm .1; .2:

Color:

Very dark grey coat. Moderate general roughness.

CORROSION:

Wt. of coat, mg/cm² 0.14

Overall metal lost,
µg/cm²/hr. 0.92

Corrosion rate, µg/cm²/hr. 2.0 (0-50 hrs.)
0.28 (50-400 hrs.)

OBJECT:

To determine the corrosion of 72S aluminum at the following conditions:

CONDITIONS: - (Average thruout run)

pH 6.9 Temp., °C. 90
N H₂O₂ 2 x 10⁻⁶ Vel., ft./sec. 23
ppm Cl⁻ 1 Hrs. in test 401½
ppm Ca⁺⁺ 1.8 Date finished 1/22/44
ppm SO₄⁼ 8.9
ppm Mg⁺⁺ 0.5

APPEARANCE:

Pits: Number 1-2
Depth, mm 0.4
Diameter at top, mm .45

Color:

Bright and light gray.

CORROSION:

Wt. of coat, mg/cm² 0.30

Overall metal lost,
µg/cm²/hr. 1.80

Corrosion rate, µg/cm²/hr. 1.3

2.49-235

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: - (Average thruout run)

pH 6.6

Temp., °C. 79

$$\text{N H}_2\text{O}_2 \quad \underline{2 \times 10^{-5}}$$

Vel., ft./sec. 20

ppm Cl⁻ 1.0

Hrs. in test 410

ppm Ca^{++} 21

Date finished 1-31-44

ppm SO_4^{2-} 82

ppm Mg^{++} 3

APPEARANCE:

Hits: Number Sent

Roughened surface

Depth, mm .1 and .2

Diameter at top, mm .6

Color: Dark grey coat, black adhesive material in some spots.

CORRECTION:

Wt. of coat, mg/cm² 0.31

Overall metal lost,
 $\mu\text{g}/\text{cm}^2/\text{hr.}$ 1.64

Corrosion rate, $\mu\text{g}/\text{cm}^2/\text{hr.}$ 0.47 (0-90 hrs.)
2.96 (90-400 hrs.)

S-49-236

OBJECT:

To determine the corrosion of 2S aluminum under the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>6.6</u>	Temp., °C. <u>94</u>
N H ₂ O ₂ <u>1.2 x 10⁻⁴</u>	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>1.2</u>	Hrs. in test <u>407</u>
ppm Ca ⁺⁺ <u>24</u>	Date finished <u>2-1-44</u>
ppm SO ₄ ⁻ <u>143</u>	
ppm Mg ⁺⁺ <u>5.1</u>	

APPEARANCE:

Pits: Number None
Depth, mm
Diameter at top, mm
Color: Bright, light grey coat

Roughened surface

CORROSION:

Wt. of coat, mg/cm² .48
Corrosion rate, µg/cm²/hr. 0.25

Overall metal lost,
µg/cm²/hr. 2.40

S-49-238

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: - (Average thruout run)

pH 5.9 Temp., °C. 80
N H₂O₂ 1.1 x 10⁻⁴ Vel., ft./sec. 15
ppm Cl⁻ 1.1 Hrs. in test 397½
ppm Ca⁺⁺ 23 Date finished 2-1-44
ppm SO₄⁼ 112
ppm Mg ⁺⁺ 4

APPEARANCE:

Fits: Number None
Depth, in Moderate roughness
Diameter at top, mm
Color: Bright, light grey.

CORROSION:

Wt. of coat, mg/cm² 0.79 Overall metal lost, 2.39 µg/cm²/hr.
Corrosion rate, µg/cm²/hr. 25 (50-400 hrs.)

L-49-238

02/21:

To determine the corrosion of 72S aluminum at the following conditions:

CONDITIONS: - (Average thruout run)pH 5.5Temp., °C. 80N H₂O₂ 1.3 x 10⁻³Vel., ft./sec. 20ppm Cl⁻ 1.3Hrs. in test 400¹ppm Ca⁺⁺ 22Date finished 2-10-44ppm SO₄⁼ 89ppm Mg⁺⁺ 5.4APPEARANCE:

Pits: Number - Few
Depth, mm .1-.2
Diameter at top,
mm 6-.8

Roughened surface.

Color: Medium grey with black streaks.CORROSION:Wt. of coat, mg/cm² .16Overall metal lost,
µg/cm²/hr. 1.22Corrosion rate, µg/cm²/hr. 1.4 (0-150 hrs.)
0.54 (150-400 hrs.)

40-239

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 5.0Temp., °C. 70N H₂O₂ 0.9 x 10⁻⁴Vel., ft./sec. 9ppm Cl⁻ 0Hrs. in test 417ppm Ca⁺⁺ 25Date finished 2-19-44ppm SO₄⁼ 99ppm Mg⁺⁺ 7.8APPEARANCE:Pits: Number NoneDepth, mm Diameter at top, mm

Mild roughness.

Color: Light greyCORROSION:Wt. of coat, mg/cm². 0.12

Overall metal lost;

µg/cm²/hr. 0.66Corrosion rate, µg/cm²/hr. 0.43 (50-400 hrs.)

OBJECT:

To determine corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.2

Temp., °C. 95

N H₂O₂ 1.1 x 10⁻⁴

Vel., ft./sec. 9

fpm Cl⁻ 0

Hrs. in test 412

ppm Ca⁺⁺ 26

Date finished 2-19-44

ppm SO₄⁼ 104ppm Mg⁺⁺ 9.6APPEARANCE:

Pits: Number None

Depth, mm

Diameter at top, mm

Moderate roughness.

Color: Light tan

CORROSION:Wt. of coat, mg/cm² 0.55

Overall metal lost,

μg/cm²/hr. 11.64Corrosion rate, μg/cm²/hr. 0.63 (0-200 hrs.)

0.27 (200-400 hrs.)

S-49-241

CORROSION TEST RUN

OBJLCT:

To determine corrosion of 2S aluminum at the following conditions:

CONDITIONS: - (Average thruout run)pH 6.0Temp., °C. 78M H₂O₂ 1 x 10⁻⁶Vel., ft./sec. 23ppm Cl⁻ 1.0Hrs. in test 400ppm Ca⁺⁺ 23Date finished 2-19-44ppm SO₄⁻ 82Sat. with N₂ gasppm Mg⁺⁺ 7.3O₂ = ~0.10 ppmAPPEARANCE:Fits: Number teNoneDepth, mm

Moderate roughness.

Diameter at top, mm

Color: Light grey.

CORROSION:wt. of coat, mg/cm² 0.27Overall metal lost,
µg/cm²/hr. 0.80Corrosion rate, µg/cm²/hr. 0.09 (0-175 hrs.)
0.24 (175-400 hrs.)

S-49-242

CORROSION TEST RUN

Run No. 120

Data - N.B. # 430B Page 4

OBJECT:

to determine corrosion of 2S aluminum at the following conditions:

CONDITIONS: - (Average thruout run)

pH 5.9 Temp., °C. 70
N H₂O₂ 3×10^{-6} Vel., ft./sec. 15
ppm Cl⁻ 1.1 Hrs. in test 417
ppm Ca⁺⁺ 24 Date finished 2-19-44
ppm SO₄⁼ 96
ppm Mg ⁺⁺ 7.9

APPEARANCE:

Pits: Number None
Depth, mm
Diameter at top, mm

Mild roughness.

Color: Medium Gray

CORROSION:

Wt. of coat, mg/cm² 0.17 Overall metal lost,
Corrosion rate, µg/cm²/hr. 0.20 (100-400 hrs.) µg/cm²/hr. 0.56

~~SECRET~~

A-49-243

OBJECT:

To determine the corrosion of 2S aluminum under the following conditions:

CONDITIONS: = (Average thruout run)

pH 5.9 Temp. °C. 80
N H₂O₂ 1 x 10⁻⁶ Vel., ft./sec. 15
ppm Cl⁻ 1.1 Hrs. in test 417
ppm Ca⁺⁺ 24 Date finished 2-19-44
ppm SO₄⁼ 102
ppm Mg ⁺⁺ 8.7

APPEARANCE:

Fits: Number None
Depth, mm mm
Diameter at top, Moderate roughness.
Color: Light Grey.

CORROSION:

Wt. of coat, mg/cm² 0.24 Overall metal lost, 0.69 µg/cm²/hr.
Corrosion rate, µg/cm²/hr. 0.3 (100-400 hrs.)

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 6.1Temp., °C. 94N H₂O₂ 1.3×10^{-5} Vel., ft./sec. 9ppm Cl⁻ 1.2Hrs. in test 430ppm Ca⁺⁺ 30Date finished 3-2-44ppm SO₄ 121ppm Mg⁺⁺ 0.9APPEARANCE:

Pits: Number Few
Depth, mm 0.16
Diameter at top, mm 0.3

Roughed surface.

Color:

CORROSION:Wt. of coat, mg/cm² 0.32Overall metal lost,
μg/cm²/hr. 2.09

Corrosion rate, μg/cm²/hr. 3.0 (0-200 hrs.)
2.4 (200-400 hrs.) } Av. of 3 samples
0.68 - 2 Samples
One sample seriously pitted; the other two,
very little

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.3

Temp., °C. 78

N H₂O₂ 1 X 10⁻⁶

Vel., ft./sec. 23

ppm Cl^- 1.2

Hrs. in test 382 $\frac{1}{2}$

ppm Ca^{++} 19

Date finished 3-2-44

ppm SO_2 77

Soln. sat. with O_2 gas

ppm Mg^{++} 6.3

APPEARANCE:

Pits: Number None

Depth, mm

Diameter at top, mm _____

Color:

Mild general roughness. Medium gray.

CORROSION:

Wt. of coat, mg/cm² 0.21

Overall metal lost,
 $\mu\text{g}/\text{cm}^2/\text{hr.}$ 0.66

Corrosion rate, $\mu\text{g}/\text{cm}^2/\text{hr.}$ $\frac{0.6}{0.09} \frac{(0-100 \text{ hrs.})}{(100-400 \text{ hrs.})}$

S-49-246

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH	5.0	Temp., °C.	94
N H ₂ O ₂	1.2×10^{-4}	Vel., ft./sec.	20
ppm Cl ⁻	1.2	Hrs. in test	417
ppm Ca ⁺⁺	20	Date finished	3-4-44
ppm SO ₄ ⁻	75		
ppm Mg ⁺⁺	6.4		

APPEARANCE:

Pits: Number Few
Depth, mm 0.08-0.1
Diameter at top, mm 0.0-0.6 Roughed surface
Color:
Dark gray.

CORROSION:

Wt. of coat, mg/cm² 0.35 Overall metal lost,
µg/cm²/hr. 1.44
Corrosion rate, µg/cm²/hr. 0.35 (0-150 hrs.)
0.69 (150-400 hrs.)

S-49-247

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.6 Temp., °C. 94
N H₂O₂ 2.9×10^{-5} Vel., ft./sec. 9
ppm Cl⁻ 0 Hrs. in test 409
ppm Ca⁺⁺ 30 Date finished 3-17-44
ppm SO₄⁼ 114
ppm Mg⁺⁺ 10.9

APPEARANCE:

Pits: Number 1 one
Depth, mm _____
Diameter at top, mm _____

Color:

Light gray. Moderate general roughness.

CORROSION:

Wt. of coat, mg/cm² 0.57

Overall metal lost,
µg/cm²/hr. 1.52

Corrosion rate, µg/cm²/hr. 0.16 (100-400 hrs.)

S-49-246

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>6.6</u>	Temp., °C. <u>95</u>
N H ₂ O ₂ <u>1x10⁻⁶</u>	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>0</u>	Hrs. in test <u>409</u>
ppm Ca ⁺⁺ <u>0</u>	Date finished <u>3-17-44</u>
ppm SO ₄ ⁼ <u>4</u>	
ppm Mg ⁺⁺ <u>0</u>	

APPEARANCE:

Pits: Number None
Depth, mm Mild general roughness.
Diameter at top, mm
Color:
Bright--light gray.

CORROSION:

Wt. of coat, mg/cm² 0.86 Overall metal lost,
μg/cm²/hr. 2.08
Corrosion rate, μg/cm²/hr. 0.13 (100-400 hrs.)

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH	6.9	Temp., °C.	80
N H ₂ O ₂	1×10^{-6}	Vel., ft./sec.	23
ppm Cl ⁻	0.4	Hrs. in test	409
ppm Ca ⁺⁺	20	Date finished	3-17-44
ppm SO ₄ ⁼	71		
ppm Mg ⁺⁺	6.8		

APPEARANCE:

Pits: Number None Moderate roughness.
Depth, mm
Diameter at top, mm
Color: Light tan.

CORROSION:

Wt. of coat, mg/cm² 1.5 Overall metal lost, 4.78 $\mu\text{g/cm}^2/\text{hr.}$
Corrosion rate, $\mu\text{g/cm}^2/\text{hr.}$ 1.3 (100-400 hrs.)

~~SECRET~~

S-49-250

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>6.4</u>	Temp., °C. <u>70</u>
N H ₂ O ₂ <u>2x10⁻⁵</u>	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>0</u>	Hrs. in test <u>409</u>
ppm Ca ⁺⁺ <u>83</u>	Date finished <u>3-17-44</u>
ppm SO ₄ ⁼ <u>81</u>	
ppm Mg ⁺⁺ <u>7.3</u>	

APPEARANCE:

Pits: Number _____
 Depth, mm _____
 Diameter at top, mm _____

Color: Medium dark gray. Mild general roughness.

CORROSION:

Wt. of coat, mg/cm² 0.19 Overall metal lost, 0.53 $\mu\text{g/cm}^2/\text{hr.}$
 Corrosion rate, $\mu\text{g/cm}^2/\text{hr.}$ 0.2 (100-400 hrs.)

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH	5.9	Temp., °C.	95
N H ₂ O ₂	1.7×10^{-5}	Vel., ft./sec.	9
ppm Cl ⁻	0	Hrs. in test	409
ppm Ca ⁺⁺	30	Date finished	3-17-47
ppm SO ₄ ⁼⁼	100		
ppm Mg ⁺⁺	7.9		

APPEARANCE:

Pits: Number _____
Depth, mm _____
Diameter at top, mm _____

Color:

Medium gray. Moderate general roughness.

CORROSION:

Wt. of coat, mg/cm² 0.70

Overall metal lost,
μg/cm²/hr. 1.92

Corrosion rate, μg/cm²/hr. 0.49 (100-400 hrs.)

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.7

Temp., °C. 94

N H₂O₂ 1.5x10⁻⁵

Vel., ft./sec. 9

ppm Cl⁻ 0

Hrs. in test 401

ppm Ca⁺⁺ 0

Date finished 3-24-44

ppm SO₄ 4ppm Mg⁺⁺ 0APPEARANCE:

Notes: Notes
Depth, in
Diameter at top, in

Color:

Light gray. Moderate general roughness.

CORROSION:Wt. of coat, mg/cm² 0.55Overall metal lost,
μg/cm²/hr. 2.3Corrosion rate, μg/cm²/hr. 0.12 (50-400 hrs.)

S-49-253

CORROSION TEST RUN

Run No. 131Data - N.B. # 430 B Page 67OBJECT:

To determine the corrosion of 72S aluminum at the following conditions:

CONDITIONS: - (Average thruout run)

pH <u>6.6</u>	Temp., °C. <u>70</u>
N H ₂ O ₂ <u>1.8×10^{-4}</u>	Vel., ft./sec. <u>20</u>
ppm Cl ⁻ <u>0.8</u>	Hrs. in test <u>401</u>
ppm Ca ⁺⁺ <u>20</u>	Date finished <u>3-25-44</u>
ppm SO ₄ ⁻² <u>73</u>	
ppm Mg ⁺⁺ <u>6.4</u>	

APPEARANCE:

Pits: Number Moderate
 Depth, mm 0.01
 Diameter at top, mm

Color: Moderate roughness. Medium gray.

CORROSION:

Wt. of coat, mg/cm² 0.88 Overall metal lost, 1.85 ug/cm²/hr.
 Corrosion rate, ug/cm²/hr. 0.27 (100-400 hrs.)

~~SECRET~~

S-49-254

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 6.7Temp., °C. 93N H₂O₂ 2x10⁻⁵Vel., ft./sec. 9ppm Cl⁻ 0.9Hrs. in test 402ppm Ca⁺⁺ 24Date finished 4-8-44ppm SO₄⁼ 101ppm SiO₂ 2.5ppm Mg⁺⁺ 8.9APPEARANCE:

Pits: Number _____
 Depth, mm _____
 Diameter at top, mm _____

Color:

Light brown coat. Moderate roughness.

CORROSION:Wt. of coat, mg/cm² 1.5

Overall metal lost,
 µg/cm²/hr. 4.8

Corrosion rate, µg/cm²/hr. 1.6(0-250 hrs.)
0.6(250- 400 hrs.)

S-49-255

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 6.7Temp., °C. 93N H₂O₂ 1.7 x 10⁻⁵Vel., ft./sec. 9ppm Cl⁻ 0.8Hrs. in test 418ppm Ca⁺⁺ 23Date finished 4-10-44ppm SO₄⁼ 96ppm SiO₂ 4.7ppm Mg⁺⁺ 8.7APPEARANCE:Pits: Number NoneDepth, mm Diameter at top, mm

Color:

Dark brown coat. Moderate roughness.

CORROSION:Wt. of coat, mg/cm² 2.95Overall metal lost,
μg/cm²/hr. 10.9Corrosion rate, μg/cm²/hr. 7.0 (0-150 hrs.)
3.5 (150-250 hrs.)
1.6 (250-400 hrs.)

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 7.4Temp., °C. 94N H₂O₂ 2.8×10^{-5} Vel., ft./sec. 9ppm Cl⁻ 0.8Hrs. in test 402ppm Ca⁺⁺ 26Date finished 4-12-44ppm SO₄⁻ 116ppm SiO₂ = 8.6ppm Mg⁺⁺ 9.6APPEARANCE:Pits: Number NoneDepth, mm Diameter at top, mm

Color:

Very rough--dark brown. Severe roughness.

CORROSION:Wt. of coat, mg/cm² 2.1

Overall metal lost,

μg/cm²/hr. 21.6Corrosion rate, μg/cm²/hr 17.5 (0-400 hrs.)

S-49-257

~~SECRET~~
-260-

Run No. 135

CORROSION TEST RUN

Data - N.B. # 430B Page 85

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: - (Average thruout run)

Ph <u>6.7</u>	Temp., °C. <u>79</u>
N H ₂ O ₂ <u>2 x 10⁻⁶</u>	Vel., ft./sec. <u>23</u>
ppm Cl ⁻ <u>0.7</u>	Hrs. in test <u>395</u>
ppm Ca ⁺⁺ <u>20</u>	Date finished <u>4-13-44</u>
ppm SO ₄ ⁼ <u>72</u>	Soln. sat. with O ₂ gas
ppm Mg ⁺⁺ <u>6.1</u>	

APPEARANCE:

Pits: Number Two Mild roughners
Depth, mm .001
Diameter at top, mm 0.2
Color: Light gray

CORROSION:

Wt. of coat, mg/cm² 0.88 Overall metal lost, 2.3 $\mu\text{g}/\text{cm}^2/\text{hr.}$
Corrosion rate, $\mu\text{g}/\text{cm}^2/\text{hr.}$ 0.37 (200-400 hrs.)

4-13-44

8-49-258

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions.

CONDITIONS: -(Average thruout run)pH 6.1Temp., °C. 80N H₂O₂ 1x10⁻⁶Vel., ft./sec. 22ppm Cl⁻ 0Hrs. in test 394ppm Ca⁺⁺ 0Date finished 4-8-44ppm SO₄⁻² 0ppm Mg⁺⁺ 0APPEARANCE:Pits: Number NoneDepth, mm Diameter at top, mm

Color:

Medium gray. Mild roughness

CORROSION:Wt. of coat, mg/cm² 0.12Overall metal lost,
µg/cm²/hr. 0.3Corrosion rate, µg/cm²/hr. 0.16(100-400 hrs.)

CORROSION TEST PLAN

Run No. 137Data - N.B.# 430B Page 87OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 7.1Temp., °C. 80N H₂O₂ 1.7 x 10⁻⁵Vel., ft./sec. 15ppm Cl⁻ 0.9Hrs. in test 394ppm Ca⁺⁺ 28Date finished 4-8-44ppm SO₄⁻² 119ppm SiO₂ 5.2ppm Mg⁺⁺ 10.2APPEARANCE:Pits: Number NoneDepth, mm Diameter at top, mm

Color:

Dark brown coat, roughened surface.

CORROSION:Wt. of coat, mg/cm² 1.5Overall metal lost,
μg/cm²/hr. 7.6Corrosion rate, μg/cm²/hr. 4.0 (100-250 hrs.)
2.7 (250-400 hrs.) ~~SECRET~~

S-49-260

Run No. 138

CORROSION TEST RUN

Data - N.B. # 430 B Page 88OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.6 Temp., °C. 71
 N H₂O₂ 1.8 x 10⁻⁵ Vel., ft./sec. 15
 ppm Cl⁻ 1.0 Hrs. in test 394
 ppm Ca⁺⁺ 24 Date finished 4-8-44
 ppm SO₄ 97
 ppm Mg⁺⁺ 8.6

APPEARANCE:

Pits: Number None
 Depth, mm _____
 Diameter at top, mm _____

Color:

Slight roughness. Medium gray. Roughened surface.

CORROSION:

Wt. of coat, mg/cm² 0.29 Overall metal lost, 0.93 µg/cm²/hr.
 Corrosion rate, µg/cm²/hr. 0.39 (150-400 hrs.)

S-49-261

OBJECT:

To determine the corrosion of 72S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH	6.5	Temp., °C.	94
N H ₂ O ₂	0.6 x 10 ⁻⁴	Vel., ft./sec.	20
ppm Cl ⁻	1.0	Hrs. in test	407
ppm Ca ⁺⁺	20	Date finished	4-24-44
ppm SO ₄ ²⁻	77		
ppm Mg ⁺⁺	7.4		

APPEARANCE:

Pits: Number Moderate
Depth, mm 0.1-0.2
Diameter at top, mm 0.2-0.5

Color:

Medium gray--slight general roughness.

CORROSION:

Wt. of coat., mg/cm² 0.55 Overall metal lost, 3.3 $\mu\text{g}/\text{cm}^2/\text{hr.}$
Corrosion rate, $\mu\text{g}/\text{cm}^2/\text{hr.}$ 7.9 (0-100 hrs.)
0.16(150-400 hrs.)

SECRET

S-14-262

CORROSION TEST RUN

Run No. 140Data - N.B.#430 B Page 125OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.5 Temp., °C. 70
 N H₂O₂ 1 x 10⁻⁵ Vel., ft./sec. 9
 ppm Cl⁻ 1.3 Hrs. in test 409
 ppm Ca⁺⁺ 26 Date finished 5-4-44
 ppm SO₄⁻ 104
 ppm Mg⁺⁺ 9.6

APPEARANCE:

Pits: Number None
 Depth, mm
 Diameter at top, mm

Color:
 Medium gray--mild general roughness.

CORROSION:

Wt. of coat, mg/cm² 0.23 Overall metal lost,
 µg/cm²/hr. 0.63
 Corrosion rate, µg/cm²/hr. 0.07 (100-400 hrs.)

~~SECRET~~

S-69-263

CORROSION TEST RUN

Data - N.B.# 430 B Page 126OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.7 Temp., °C. 70
 NH_2O_2 1×10^{-5} Vel., ft./sec. 9
 ppm Cl^- 1.1 Hrs. in test 409
 ppm Ca^{++} 23 Date finished. 5-4-44
 ppm SO_4^{--} 94
 ppm Mg^{++} 8.1

APPEARANCE:

Pits: Number None
 Depth, mm
 Diameter at top, mm

Color:

Mild general roughness. Medium gray.

CORROSION:

Wt. of coat, mg/cm² 0.41 Overall metal lost,
 $\mu g/cm^2/hr.$ 1.2
 Corrosion rate, $\mu g/cm^2/hr.$ 0.28 (50-400 hrs.)

S-49-264

CORROSION TEST RUN

Data - N.B.# 430 B Page 127

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.9Temp., °C. 94 H_2O_2 0.5 ~ 10⁻⁵Vel., ft./sec. 9ppm Cl^- 1.2Hrs. in test 409ppm Ca^{++} 30Date finished 5-4-44ppm SO_4^{--} 125ppm Mg^{++} 11.2APPEARANCE:Pits: Number NoneDepth, mm -Diameter at top, mm -

Color.

Moderate general roughness. Light tan.

CORROSION:Wt. of coat, mg/cm² 2.1

Overall metal lost,

 $\mu\text{g}/\text{cm}^2/\text{hr.}$ 6.3Corrosion rate, $\mu\text{g}/\text{cm}^2/\text{hr.}$ 1.2 (50-400 hrs.)

SECRET

S-49-265

CORROSION TEST RUN

Run No. 143

Data - N.B.# 430 B Page 128

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH	6.2	Temp., °C.	80
N H ₂ O ₂	1×10^{-5}	Vel., ft./sec.	25
pp m Cl ⁻	0.8	Hrs. in test	407
ppm Ca ⁺⁺	20	Date finished	5-2-44
ppm SO ₄ ⁼	64	pp W.S.L	5
ppm Mg ⁺⁺	8.7		

APPEARANCE:

Pits: Number	Few	Moderate
Depth, mm	0.4 - 0.5	0.2-0.6 mm wide
Diameter at top, mm	1	0.1-0.2 mm deep

Color:

Moderate general roughness--brown discoloration.

CORROSION:

Wt. of coat, mg/cm ²	0.56	Overall metal lost,
	3.7 (0-150 hrs.)	µg/cm ² /hr. 4.3
Corrosion rate, µg/cm ² /hr.	2.4 (150-400 hrs.)

CORROSION TEST RUN

Data - N.B.# 430 B Page 129

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH	6.2	Temp., °C.	80
N H ₂ O ₂	0.8×10^{-4}	Vel., ft./sec.	20
ppm Cl ⁻	2.0	Hrs. in test	407
ppm Ca ⁺⁺	20	Date finished	5-2-44
ppm SO ₄ ⁼	79		
ppm Mg ⁺⁺	7.7		

APPEARANCE:

Pits: Number Few
Depth, mm 0.02-0.08
Diameter at top, mm 0.1-0.3

Color:

Medium gray. Slight general roughness.

CORROSION:

Wt. of coat, mg/cm² 0.17 Overall metal lost,
µg/cm²/hr. 0.9
Corrosion rate, µg/cm²/hr. 0.42 (50-400 hrs.)

S-49-247

CORROSION TEST RUN

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>6.5</u>	Temp., °C. <u>70</u>
N H ₂ O ₂ <u>1.4 x 10⁻⁵</u>	Vel., ft./sec. <u>15</u>
ppm Cl ⁻ <u>1.2</u>	Hrs. in test <u>409</u>
ppm Ca ⁺⁺ <u>25</u>	Date finished <u>5-4-44</u>
ppm SO ₄ ⁼ <u>101</u>	
ppm Mg ⁺⁺ <u>8.9</u>	

APPEARANCE:

Pits: Number None
 Depth, mm
 Diameter at top, m

Color:

Medium gray. Mild general roughness.

CORROSION:

Wt. of coat, mg/cm ² <u>0.29</u>	Overall metal lost, <u> </u>
	μg/cm ² /hr. <u>1.1</u>
Corrosion rate, μg/cm ² /hr. <u>0.33 (100-250 hrs.)</u>	
<u>0.17 (250-400 hrs.)</u>

CORROSION TEST RUN

Data - N.B.# 430 B Page 131

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 6.6Temp., °C. 79N H₂O₂ 1.3 x 10⁻⁵Vel., ft./sec. 15ppm Cl⁻ 1.4Hrs. in test 409ppm Ca⁺⁺ 26Date finished 5-4-44ppm SO₄⁼ 107ppm Mg⁺⁺ 9.6APPEARANCE:

Pits: Number Two Few
 Depth, mm 0.1 .05-0.1
 Diameter at top, mm 0.8 .0.1-0.4

Color:

Medium gray--mild general roughness.

CORROSION:Wt. of coat, mg/cm² 0.29Overall metal lost,
μg/cm²/hr. 1.1Corrosion rate, μg/cm²/hr. 0.78 (150-350 hrs.)

CORROSION TEST RUN

Run No. 147Data - N.B.# 430 B Page 132OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 5.7Temp., °C, 80N H₂O₂ 0.8 x 10⁻⁴Vel., ft./sec. 25ppm Cl⁻ 1.1Hrs. in test 405ppm Ca⁺⁺ 20Date finished 5-5-44ppm SO₄⁼ 80ppm Mg⁺⁺ 7.3APPEARANCE:

Pits: Number Moderate
 Depth, mm .001-0.1
 Diameter at top, mm 0.1-0.4

Color:

Medium gray--mild general roughness.

CORROSION:Wt. of coat, mg/cm² 0.26Overall metal lost,
μg/cm²/hr. 3.0Corrosion rate, μg/cm²/hr. 1.4 (100-400 hrs.)

10-270

CORROSION TEST RUN

Run No. 148

Data - N.B.# 430 B Page 150

SUBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>6.2</u>	Temp., °C. <u>93</u>
N H ₂ O ₂ <u>0.6 x 10⁻⁵</u>	Vel., ft./sec. <u>22</u>
ppm Cl ⁻ <u>1.2</u>	Hrs. in test <u>386</u>
ppm Ca ⁺⁺ <u>20</u>	Date finished <u>5-13-44</u>
ppm SO ₄ ⁼ <u>79</u>	
ppm Mg ⁺⁺ <u>6.9</u>	

APPEARANCE:

Pits: Number None
Depth, mm
Diameter at top, mm

Color:

Medium gray, moderate roughness.

CORROSION:

Wt. of coat, mg/cm ² <u>0.24</u>	Overall metal lost, <u> </u>
	µg/cm ² /hr. <u>0.84</u>
Corrosion rate, µg/cm ² /hr. <u>0.11 (100-400 hrs.)</u>

Run No. 149

CORROSION TEST RUN

Data - N.B.# 430 B Page 151OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 6.2Temp., °C. 72N H₂O₂ 1.2 x 10⁻⁵Vel., ft./sec. 25ppm Cl⁻ 0.9Hrs. in test 407ppm Ca⁺⁺ 20Date finished 5-16-44ppm SO₄⁼ 79ppm Mg⁺⁺ 6.8APPEARANCE:Pits: Number _____
Depth, mm _____
Diameter at top, mm _____Few
0.1-0.2
0.6

Color:

Medium gray--moderate roughness.

CORROSION:Wt. of coat, mg/cm² 0.25Overall metal lost,
μg/cm²/hr. 2.7Corrosion rate, μg/cm²/hr. 1.3 (100-400 hrs.)

S-49-272

CORROSION TEST RUN

Data - N.B.# 430 B Page 168

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 4.5Temp., °C. 80N H₂O₂ 0.8 x 10⁻⁴Vel., ft./sec. 25ppm Cl⁻ 1.0Hrs. in test 408ppm Ca⁺⁺ 20Date finished 5-23-44ppm SO₄⁼ 75ppm Na₂Cr₂O₇·2H₂O 2.3ppm Mg⁺⁺ 7.3

APPEARANCE:

Pits: Number None
Depth, mm
Diameter at top, mm

Very slight roughness.

Color:

Dull, medium gray.

CORROSION:

Wt. of coat, mg/cm² 0.06Overall metal lost,
μg/cm²/hr. 0.48Corrosion rate, μg/cm²/hr. 0.13 (0-150 hrs.)
0.38 (150-400 hrs.)

CORROSION TEST RUN

Run No. 151

Data - N.B.# 430 B Page 169

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 5.5

Temp., °C. 80

N H₂O₂ 1.1 x 10⁻⁴

Vel., ft./sec. 22

ppm Cl⁻ 1.1

Hrs. in test 408

ppm Ca 20

Date finished 5-23-44

ppm SO₄⁼ 76

ppm Na₂Cr₂O₇·2H₂O 2.5

ppm Mg⁺⁺ 6.8

APPEARANCE:

Pits: Number None

Depth, mm

Diameter at top, mm

Color:

Dull, dark gray. Mild roughness

CORROSION:

Wt. of coat, mg/cm² 0.13

Overall metal lost,
μg/cm²/hr. 0.96

Corrosion rate, μg/cm²/hr. 0.57 (100-250 hrs.)
0.87 (250-400 hrs.)

S. 9-274

CORROSION TEST RUN

Run No. 152

Data - N.B.# 430 B Page 170

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: - (Average thruout run)

pH	5.5	Temp., °C.	80
N H ₂ O ₂	1.2×10^{-4}	Vel., ft./sec.	25
ppm Cl ⁻	1.0	Hrs. in test	408
ppm Ca ⁺⁺	20	Date finished	5-23-44
ppm SO ₄ ⁻	73	ppm Na ₂ CrO ₇ · 2H ₂ O	5.9
ppm Mg ⁺⁺	7.8		

APPEARANCE:

Pits: Number Few
 Depth, mm .001 .05
 Diameter at top, mm .05-0.2

Color:

Much roughness--dull, medium gray.

CORROSION:Wt. of coat, mg/cm² 0.17Overall metal lost,
μg/cm²/hr. 1.7Corrosion rate, μg/cm²/hr. 1.1 (100-250 hrs.)
1.9 (250-400 hrs.)

CORROSION TEST RUN

Run No. 153

Data - N.B.# 430 B Page 181

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.5

Temp., °C 70

N H₂O₂ 1 x 10⁻⁶

Vel., ft./sec. 9

ppm Cl⁻ 1.1

Hrs. in test 397

ppm Ca⁺⁺ 23

Date finished 5-29-44

ppm SO₄⁼ 85ppm Mg⁺⁺ 8.2APPEARANCE:

Pits: Number None

Depth, mm

Diameter at top, mm

Color:

Slight general roughness. Light gray.

CORROSION:Wt. of coat, mg/cm² 0.35Overall metal loss,
μg/cm²/hr. 1.06Corrosion rate, μg/cm²/hr. 0.20 (100-200 hrs.)
0.44 (200-400 hrs.)

S. 49-274

CORROSION TEST RUN

Run No. 154

Data - N.B. #4308 Page 182

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.5

Temp., °C 70

N H₂O₂ 1.1 x 10⁻⁴

Vel., ft./sec. 9

ppm Cl⁻ 1.1

Hrs. in test 397

ppm Ca⁺⁺ 25

Date finished 5-29-44

ppm SO₄⁼⁼ 100ppm Mg⁺⁺ 9.4APPEARANCE:

Pits: Number None

Depth, mm

Diameter at top, mm

Color:

Moderate general roughness. Medium gray.

CORROSION:Wt. of coat, mg/cm² 0.29Overall metal lost,
ug/cm²/hr. 0.84Corrosion rate, ug/cm²/hr. 0.28 (150-400 hrs.)

S-49-277

CORROSION TEST RUN

Run No. 155Data - N.B.# 430 B Page 183OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 5.9Temp., °C 70N H₂O₂ 1.2 x 10⁻⁴Vel., ft./sec. 9ppm Cl⁻ 1.2Hrs. in test 397ppm Ca⁺⁺ 23Date finished 5-29-44ppm SO₄⁼ 83ppm Mg⁺⁺ 8.1APPEARANCE:Pits: Number FewDepth, mm .05-.1:Diameter at top, mm .1-.25:

Color:

Medium gray. Moderate roughness.

CORROSION:Wt. of coat, mg/cm² 0.20Overall metal lost,
μg/cm²/hr. 0.96Corrosion rate, μg/cm²/hr. 0.41

SECRET

S-49-278

CORROSION TEST RUN

Data - N.B# 430B Page 184

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 3.0

Temp., °C 70

N H₂O₂ 2 x 10⁻⁵

Vel., ft./sec. 25

ppm Cl⁻ 1.0

Hrs. in test 113

ppm Ca⁺⁺ 20

Date finished 6-1-44

ppm SO₄⁼ 74ppm H₂C₂O₄ added = 50 ppmppm Mg⁺⁺ 7.6APPEARANCE:

Pits: Number None
 Depth, mm
 Diameter at top, mm

Color;
 Slight roughness--light gray.

CORROSION:Wt. of coat, mg/cm² 0.22Overall metal lost,
μg/cm²/hr. 106Corrosion rate, μg/cm²/ hr. 103 (0-113 hrs.)

8-49-2177

CORROSION TEST RUN

Run No. 157Date - N.B.# 430 B Page 185SUBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>6.1</u>	Temp., °C. <u>93</u>
N H ₂ O ₂ <u>0.8 x 10⁻⁴</u>	Vel., ft./sec. <u>22</u>
ppm Cl ⁻ <u>1.3</u>	Hrs. in test <u>372</u>
ppm Ca ⁺⁺ <u>20</u>	Date finished <u>6-1-44</u>
ppm SO ₄ ⁻ <u>75</u>	
ppm Mg ⁺⁺ <u>7.2</u>	

APPEARANCE:

Pits: Number None
 Depth, mm
 Diameter at top, mm

Color:

Moderate roughness--light tan.

CORROSION:Wt. of coat, mg/cm² 0.55Overall metal lost,
μg/cm²/hr. 2.3Corrosion rate, μg/cm²/hr. 1.4 (0-200 hrs.)
0.23 (200-400 hrs.) ~~SECRET~~

S-49-280

CORROSION TEST RUN

Run No. 158

Date - N.B.# 430 B Page 186

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 3.5

Temp., °C 70

N H₂O₂ 2x10⁻⁵

Vel., ft./sec. 23

ppm Cl⁻ 1

Hrs. in test 113

ppm Ca⁺⁺ 20

Date finished 6-1-44

ppm SO₄²⁻ 72ppm C₂H₂O₄ added = 50ppm Mg⁺⁺ 7.0APPEARANCE:

Pits: Number No visible pitting
Depth, mm _____
Diameter at top, mm _____

Moderate roughness. Serious wt. loss due to
aluminum going into solution uniformly and
not because of pitting.

Color:

Medium, dull gray.

CORROSION:Wt. of coat, mg/cm² 0.18Overall metal lost,
μg/cm²/hr. 57Corrosion rate, μg/cm²/hr. 56 (0-113 hrs.)

SECRET

J. 47-281

Run No. 159

CORROSION TEST RUN

Data - N.B.# 430 B Page 187OBJECT:

To determine the corrosion of 2S aluminum at the following conditions: .

CONDITIONS: -(Average thruout run)

pH 6.7 Temp., °C. 70
N H₂O₂ 1 x 10⁻⁵ Vel., ft./sec. 15
ppm Cl⁻ 1.0 Hrs. in test 397
ppm Ca⁺⁺ 24 Date finished 5-29-44
ppm SO₄⁻ 90
ppm Mg⁺⁺ 8.5

APPEARANCE:

Pits: Number Few
Depth, mm .1-.2
Diameter at top, mm .3-.4

Color:

Medium gray--slight roughness.

CORROSION:

Wt. of coat, mg/cm² 0.39 Overall metal lost, 1.6 µg/cm²/hr.
Corrosion rate, µg/cm²/hr. 0.83 (50-400 hrs.)

S. 49-282

CORROSION TEST RUN

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>6.7</u>	Temp., °C. <u>80</u>
N H ₂ O <u>1 x 10⁻⁵</u>	Vel., ft./sec. <u>15</u>
ppm Cl ⁻ <u>1.0</u>	Hrs. in test <u>397</u>
ppm Ca ⁺⁺ <u>27</u>	Date finished <u>5-29-44</u>
ppm SO ₄ ⁻ <u>108</u>	
ppm Mg ⁺⁺ <u>9.7</u>	

APPEARANCE:

Pits: Number Few
 Depth, mm .1-.2
 Diameter at top, mm .3-.4
 Color: Slight roughness. Medium gray.

CORROSION:

Wt. of coat, mg/cm² 0.78
 Corrosion rate, µg/cm²/hr. 0.57

Overall metal lost,
 µg/cm²/hr. 2.3

S-49-283

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 4.0

Temp., °C 70

N H₂O₂ 2 x 10⁻⁵

Vel., ft./sec. 25

ppm Cl⁻ 1.0

Hrs. in test 113

ppm Ca⁺⁺ 20

Date finished 6-1-44

ppm SO₄⁼ 70ppm C₂H₂O₄ added = 50 ppmppm Mg⁺⁺ 8.4APPEARANCE:

Pits: Number _____
Depth, mm _____
Diameter at top, mm _____

Color:

Moderate roughness-light tan.

CORROSION:Wt. of coat, mg/cm² 0.27Overall metal lost,
μg/cm²/hr. 32Corrosion rate, μg/cm²/hr. 30 (0-113 hrs.)

S-49-284

Run No 162

CORROSION TEST RUN

Data - N.B.# 430 B Page 190

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 4.8

N H₂O₂ 2×10^{-4}

ppm Cl⁻ 1.0

ppm Ca⁺⁺ 20

ppm SO₄⁼ 76

ppm Mg⁺⁺ 7.0

Temp., °C. 70

Vel., ft./sec. 25

Hrs. in test 432

Date finished 6-1-44

ppm Na₂Cr₂O₇·2H₂O 6

APPEARANCE:

Pits: Number	Few
Depth, mm	.01
Diameter at top, mm	.1-.2
Color:	
Black--slight roughness.	

CORROSION:

Wt of coat, mg/cm² 0.26

Corrosion rate, μg/cm²/hr. 0.62 (0-250 hrs.)
2.4 (300-450 hrs.)

Overall metal lost, μg/cm²/hr. 1.8

S-49-285

CORROSION TEST RUN

Run No. 163Data - N.B.# 1102 B Page 18OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 6.3Temp., °C. 70N H₂O₂ 3 x 10⁻⁶Vel., ft./sec. 9ppm Cl⁻ 1.1Hrs. in test 409ppm Ca⁺⁺ 22.4Date finished 6/21/44ppm SO₄⁼ 108ppm Mg⁺⁺ 6.2APPEARANCE:Pits: Number NoneDepth, mm Diameter at top, mm

Color:

Moderate roughness, light grey.

CORROSION:Wt. of coat, mg/cm² 0.21Overall metal lost,
µg/cm²/hr. 0.68Corrosion rate, µg/cm²/hr. .305 (200-400 hrs.)

CORROSION TEST RUN

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 6.0Temp., °C. 70N H₂O₂ 2.8×10^{-5} Vel., ft./sec. 9ppm Cl⁻ 1.2Hrs. in test 409ppm Ca⁺⁺ 22.0Date finished 6/21/44ppm SO₄⁼ 115ppm Mg⁺⁺ 5.6APPEARANCE:Pits: Number NoneDepth, mm Diameter at top, mm

Color:

Moderate roughness, light grey.

CORROSION:Wt. of coat, mg/cm² 0.23Overall metal lost,
µg/cm²/hr. 0.73Corrosion rate, µg/cm²/hr. .42 (150-400 hrs.)

S-49-287

CORROSION TEST RUN

Data - N.B.# 1102 B Page 20

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH	6.5	Temp., °C.	70
N H ₂ O ₂	2.2×10^{-5}	Vel., ft./sec.	9
ppm Cl ⁻	1.3	Hrs. in test	409
ppm Ca ⁺⁺	28.3	Date finished	6/21/44
ppm SO ₄ ⁼	104		
ppm Mg ⁺⁺	5.8		

APPEARANCE:

Pits: Number None
 Depth, mm
 Diameter at top, mm

Color:

Medium grey.Moderate general roughness.

CORROSION:Wt. of coat, mg/cm² 0.20Overall metal lost,
µg/cm²/hr. 0.56Corrosion rate, µg/cm²/hr. 103 (100-400 hrs.)

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 4.3Temp., °C 70V H_2O_2 12×10^{-5} Vel., ft./sec. 25ppm Cl^- 1.3Hrs. in test 405ppm Ca^{++} 19.2Date finished 6-19-44ppm SO_4^{--} 83.9ppm $K_2Cr_2O_7$ = 2.2ppm Mg^{++} 5.4ppm $H_2C_2O_4$ added = 50APPEARANCE:ppm $H_2C_2O_4$ (by analysis) = 16.4Pits: Number NoneDepth, mm Diameter at top, mm

Color:

Moderate roughness. Dark gray.

CORROSION:Vt. of coat, mg/cm² 0.10Overall metal lost,
μg/cm²/hr. 17.0Corrosion rate, μg/cm²/hr. 2.0 (250-400 hrs.)

CORROSION TEST RUN

-292-

Run No. 167

Data - N.B.# 1102 B Page 22

OBJECT:

To determine the corrosion of .2S aluminum at the following conditions:

CONDITIONS: - (Average thruout run)

pH	7.8	Temp., °C.	80
N H ₂ O ₂	1.2×10^{-4}	Vel., ft./sec.	22
ppm Cl ⁻	.1	Hrs. in test	314
ppm Ca ⁺⁺	19.5	Date finished	6-22-44
ppm SO ₄ ⁻	76	Special Conditions	
ppm Mg ⁺⁺	4.0	ppm K ₂ Cr ₂ O ₇	= 1.0

APPEARANCE:

Pits: Number None
Depth, mm
Diameter at top, mm

Color:

Moderate general roughness.

CORROSION:Wt. of coat, mg/cm² 3.63Overall metal lost,
μg/cm²/hr. 15.4Corrosion rate, μg/cm²/hr. 3.9 (0-300 hrs.)

S-49-290

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 4.1

Temp., °C. 70

N H₂O₂ 15 x 10⁻⁵

Vel., ft./sec. 22

ppm Cl⁻ 1.3

Hrs. in test 405

ppm Ca⁺² 15.7

Date Finished 6-19-44

ppm SO₄⁼ 104ppm K₂Cr₂O₇ = 2.05ppm Mg⁺⁺ 4.9ppm H₂C₂O₄ added = 50ppm H₂C₂O₄ (by analysis) = 24APPEARANCE:

Pits: Number _____
 Depth, mm _____
 Diameter at top, mm _____

Color: Mild roughness
 Medium gray.

CORROSION:Wt. of coat, mg/cm² 0.15

Overall metal lost,
 µg/cm²/hr. 51

Corrosion rate, µg/cm²/hr. 45 (100-400 hrs.)

2.4

S-49-291

CORROSION TEST RUN

Run No. 169Data - N.B.# 1102 B Page 24OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>7.2</u>	Temp., °C. <u>70</u>
N H ₂ O ₂ <u>2.7 x 10⁻⁵</u>	Vel., ft./sec. <u>15</u>
ppm Cl ⁻ <u>1.</u>	Hrs. in test <u>409</u>
ppm Ca ⁺⁺ <u>22.8</u>	Date finished <u>6/21/44</u>
ppm SO ₄ ⁻ <u>118</u>	ppm NaNO ₃ <u>3.5</u>
ppm Mg ⁺⁺ <u>6.4</u>	ppm SiO ₂ <u>6.9</u>

APPEARANCE:

Pits: Number Numerous
Depth, mm .01
Diameter at top, mm .05-.1

Color:

Much general roughness, light brown.

CORROSION:

Wt. of coat, mg/cm² 0.42 Overall metal lost,
µg/cm²/hr. 12.2
Corrosion rate, µg/cm²/hr. 13.7 (200-400 hrs.)

S-49-292

CORROSION TEST RUN

Run No. 170Data - N.B.# 1102 B Page 25OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 7.1Temp., °C. 70N H₂O₂ 3.1 x 10⁻⁵Vel., ft./sec. 15ppm Cl⁻ 1.1Hrs. in test 409ppm Ca⁺⁺ 23.0Date finished 6-21-44ppm SO₄⁻ 115ppm SiO₂ 7.2ppm Mg⁺⁺ 6.0ppm Na NO₃ 14.5APPEARANCE:

PITS: Number _____ Moderate
 Depth, mm _____ .01
 Diameter at top, mm _____ .05-.1

Color:

Much general roughness, light brown.

CORROSION:Wt. of coat, mg/cm² 0.36Overall metal lost,
μg/cm²/hr. 10.9Corrosion rate, μg/cm²/hr. 6.5 (200-400 hrs.)

S-49-293

CORROSION TEST RUN

Data - N.B.# 1102 B Page 26

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 4.2 Temp., °C 70
N H₂O₂ 17 x 10⁻⁵ Vel., ft./sec. 25
ppm Cl⁻ 1.3 Hrs. in test 405
ppm Ca⁺⁺ 15.6 Date finished 6-19-44
ppm SO₄⁻ 92.8 ppm K₂Cr₂O₇ = 1.7
ppm Mg⁺⁺ 6.3 ppm H₂C₂O₄ added = 50

APPEARANCE:ppm H₂C₂O₄ (by analysis) = 27.7

Pits: Number : Few
Depth, mm .001
Diameter at top, mm .05-.15

Color:

Bright light grey.

CORROSION:Wt. of coat; mg/cm² 0.04Overall metal lost,
µg/cm²/hr. 55Corrosion rate, µg/cm² 59 (150-400 hrs.)

S-49-294

CORROSION TEST RUN

Run No. 172

Data - N.B.# 1102 B Page 27

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>8.4</u>	Temp., °C. <u>80</u>
N H O <u>1.4 X 10⁻⁴</u>	Vel., ft./sec. <u>25</u>
2 2	
ppm Cl ⁻ <u>0.9</u>	Hrs. in test <u>314</u>
ppm Ca ⁺⁺ <u>19</u>	Date finished <u>6-19-44</u>
ppm SO ₄ ⁼ <u>79</u>	Special Conditions _____
ppm Mg ⁺⁺ <u>3.7</u>	ppm K ₂ Cr ₂ O ₇ = <u>2.1</u>

APPEARANCE:

Pits: Number Moderate
Depth, mm .001
Diameter at top, mm .05-15

Color:

Dark gray mild roughness

CORROSION:

Wt. of coat, mg/cm² 0.59

Overall metal lost,
µg/cm²/hr. 1.6

Corrosion rate, µg/cm²/hr. 1.3

CORROSION TEST RUN

-298-

Run No. 173

Data - N.B.# 11021B Page 46

OBJECT:

To determine the corrosion of 2s Aluminum at the following Conditions:

CONDITIONS: -(Average thruout run) Conductivity, reciprocal ohms per cm. 25×10^{-5}

pH	7.8	Temp., °C.	95
N H ₂ O ₂	1.6×10^{-4}	Vel., ft./sec.	25
ppm Cl ⁻	1.0	Hrs. in test	300
ppm Ca ⁺⁺	20	Date finished	7-19-44
ppm SO ₄ ⁼	69	Special Conditions	
ppm Mg ⁺⁺	4.8	ppm SiO ₂	7.5
		ppm Na ₂ Cr ₂ O ₇ · 2H ₂ O	2.5

APPEARANCE:

Pits: Number None
Depth, mm
Diameter at top, mm
Color: Dark gray moderate roughness

CORROSION:Wt. of coat, mg/cm² 2.1Overall metal lost,
μg/cm²/hr. 18.9Corrosion rate, μg/cm²/hr. 11.1 (0-300 hrs.)

SECRET

S-49-296

OBJECT:

To determine the corrosion of 2 $\frac{1}{2}$ Al at the following conditions:

CONDITIONS: -(Average thruout run) Conductivity, reciprocal ohms per cm. 26×10^{-5}

pH 8.1Temp., °C. 95N H₂O₂ 2.7×10^4 Vel., ft./sec. 22ppm Cl⁻ 1.2Hrs. in test 300ppm Ca⁺⁺ 21Date finished 7-19-44ppm SO₄⁼ 76

Special Conditions _____

ppm Mg⁺⁺ 4.5ppm SiO₂ = 8.6
ppm Na₂ Cr₂ O₇ .2H₂O = 4.8APPEARANCE:Pits: Number None

Depth, mm _____

Diameter at top, mm _____

Color:

Dark Gray Roughened surface

CORROSION:Wt. of coat, mg/cm² 0.61Overall metal lost,
µg/cm²/hr. 3.2Corrosion rate, µg/cm²/hr. 2.58 (100-300 Hrs.)
2.4 (0-100 Hrs.)

CORROSION TEST RUN

Run No. 175Data - N.B.# 1102 B Page 43OBJECT:

To determine the corrosion of 23 Al at the following conditions:

CONDITIONS: -(Average thruout run) Conductivity, reciprocal ohms per cm 26×10^{-5} pH 7.9Temp., °C. 95N H₂O₂ 3.1 10^{-4} Vel., ft./sec. 22ppm Cl⁻ 1.1Hrs. in test 300ppm Ca⁺⁺ 24Date finished 7-18-44ppm SO₄⁼ 73

Special Conditions _____

ppm Mg⁺⁺ 3.4ppm SiO₂ = 8.9
ppm Na₂Cr₂O₇ · 2H₂O = 8.4APPEARANCE:Dits: surface None

Depth, mm _____

Diameter at top, mm _____

Color:

Dark gray Roughened surface

CORROSION:Wt. of coat, mg/cm² 0.36Overall metal lost,
µg/cm²/hr. 2.5Corrosion rate, µg/cm²/hr. 0.59 (100-300 hrs.)
2.5 (0-100 hrs.)

S-49-298

~~SECRET~~

-01-

Run No. 173

CORROSION TEST RUN

Data - N.B.# 1102 B Page 49

OBJECT:

To determine the corrosion of 20 aluminum at the following conditions:

CONDITIONS: -(Average thruout run) Conductivity, reciprocal ohms per cm. 27×10^{-5}

pH <u>7.6</u>	Temp., °C. <u>95</u>
N H ₂ O ₂ <u>5.1×10^{-4}</u>	Vel., ft./sec. <u>25</u>
ppm Cl ⁻ <u>1.1</u>	Hrs. in test <u>300</u>
ppm Ca ⁺⁺ <u>23</u>	Date finished <u>7-19-44</u>
ppm SO ₄ ⁼ <u>73</u>	
ppm Mg ⁺⁺ <u>3.5</u>	ppm SiO ₂ <u>7.5</u>
	ppm Na ₂ Cr ₂ O ₇ · 2H ₂ O = <u>17.0</u>

APPEARANCE:

Number 500 Serial 500
Diameter at top, mm
Color: Dark gray Roughened surface

CORROSION:

Wt. of coat, mg/cm² 0.99 Overall metal lost,
Corrosion rate, µg/cm²/hr. 2.4 (0-100 hrs.) 1.1 (100- 500 hrs.) µg/cm²/hr. 2.8

~~SECRET~~

B-49-299

CORROSION TEST RUN

Run No. 177Data - N.B.#1102B Page 50OBJECT:

To determine the corrosion of 2s aluminum at the following conditions:

CONDITIONS: -(Average thruout run) Conductivity, reciprocal ohms per cm. 59×10^{-5} pH 3.4Temp., °C. 95N H₂O₂ 0.8×10^{-4} Vel., ft./sec. 25ppm Cl⁻ 1.3Hrs. in test 300ppm Ca⁺⁺ 22Date finished 7-19-44ppm SO₄⁻² 156

Special Conditions

ppm Mg⁺⁺ 4.9ppm Na₂Cr₂O₇ · 2H₂O = 4.8APPEARANCE:Pits: Number NoneDepth, mm Diameter at to, mm

Color:

Med. gray--extreme roughnessCORROSION:Wt. of coat, mg/cm² 0.72

Overall metal lost,

116 (100-300 hrs.)µg/cm²/hr. 101Corrosion rate, µg/cm²/hr. 73 (0-100 hrs) ~~SECRET~~

CORROSION TEST RUN

Run No. 178

Data - N.B.# 1102 B Page 62

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>4.5</u>	Temp., °C. <u>95</u>
N H ₂ O ₂ <u>1 x 10⁻⁵</u>	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>1</u>	Hrs. in test <u>310</u>
ppm Ca ⁺⁺ <u>20</u>	Date finished <u>8-11-44</u>
ppm SO ₄ ⁼ <u>90</u>	Sol oil <u>1%</u>
ppm Mg ⁺⁺ <u>6</u>	Texas Soluble oil "C" (Texaco)

APPEARANCE:

Pits: Number None Few
Depth, mm .002
Diameter at top, mm .03

Color:
Moderate roughness--light gray.

CORROSION:

Wt. of coat, mg/cm² 1.0 Overall metal lost,
Corrosion rate, µg/cm²/hr. 4.0 (150-300 hrs.) µg/cm²/hr. 4.4

849-301

Run No. 179

CORROSION TEST RUN

Date - N.B.# 1102 B Page 62OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH <u>5.5</u>	Temp., °C. <u>95</u>
N H ₂ O <u>1 x 10⁻⁵</u>	Vel., ft./sec. <u>9</u>
ppm Cl ⁻ <u>1</u>	Hrs. in test <u>310</u>
ppm Ca ⁺⁺ <u>20</u>	Date finished <u>8-11-44</u>
ppm SO ₄ ⁼ <u>30</u>	Sol oil <u>7%</u>
ppm Mg ⁺⁺ <u>6</u>	Texas Soluble oil "C" (Texaco)

APPEARANCE:

Pits: Number None
 Depth, mm
 Diameter at top, mm
 Color: Light gray--moderate roughness.

CORROSION:

Wt. of coat, mg/cm² 0.6 Overall metal lost, 1.9 µg/cm²/hr.
 Corrosion rate, µg/cm²/hr. 2.0 (100-300 hrs.)

8-49-302

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.5 Temp., °C. 95
N H₂O₂ 1 x 10⁻⁵ Vel., ft./sec. 9
ppm Cl⁻ 1 Hrs. In test 310
ppm Ca⁺⁺ 20 Date finished 8-11-44
ppm SO₄ ~90 Sol oil 7%
ppm Mg⁺⁺ 6 Texas Soluble oil "C" (Texaco)

APPEARANCE:

Pits: Number none
Depth, mm
Diameter at top, mm
Color: light gray-moderate roughness.

CORROSION:

Wt. of coat, mg/cm² 0.17 Overall metal lost, 0.5 µg/cm²/hr.
Corrosion rate, µg/cm²/hr. 0.28 - (100-300 hrs.)

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run) Conductivity, reciprocal ohms per cm. 380×10^{-5}

pH 2.0 Temp., °C. 95

N H₂O₂ 1×10^{-5} Vel., ft./sec. 24

ppm Cl⁻ 1 Hrs. in test 92

ppm Ca⁺⁺ 20 Date finished 8-14-44

ppm SO₄⁼⁼ 625 ppm SiO₂ = 10
ppm Na₂Cr₂O₇ · 2H₂O = 2

ppm Mg⁺⁺ 6

APPEARANCE:

Pits: Number _____ Tons _____

Depth, mm _____

Diameter at top, mm _____

Color: Medium gray. Much general roughness. Large weight loss due to aluminum going into solution uniformly and not because of severe pitting.

CORROSION:

Wt. of cor't., mg/cm² 0

Overall metal lost,
μf/cm²/hr. 530

Corrosion rate, μg/cm²/hr. 530 (0-92 hrs.)

~~SECRET~~

TIME (hours)

S-49-304

CORROSION TEST RUN

Data - N.B.# 1102 Page 66OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run) Conductivity, reciprocal ohms per cm. 300×10^{-5} pH 2.0Temp., °C. 95N H O 1 X 10⁻⁷
2 2Vel., ft./sec. 22ppm Cl⁻ 1Hrs. in test 92ppm Ca⁺⁺ 20Date finished 8-14-44ppm SO₄ 635

Special Conditions

ppm Mg⁺⁺ 6ppm Na₂Cr₂O₇ · 2H₂O = 8SiO₂ = 10APPEARANCE:Pits: Number NoneDepth, mm Diameter at top, mm Color:

Much general roughness. Large weight loss due to aluminum going into solution uniformly and not because of severe pitting. Medium gray.

CORROSION:Wt. of coat, mg/cm² 0Overall metal lost,
µg/cm²/hr. 544Corrosion rate, µg/cm²/hr. 544
(0-92 hrs.)

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run) Conductivity, reciprocal ohms per cm. 27×10^{-5}

pH 7.2 Temp., °C. 70

N H₂O₂ 1×10^{-5} Vel., ft./sec. 15

ppm Cl⁻ 1.1 Hrs. in test 306

ppm Ca⁺⁺ 22 Date finished 7-27-44

ppm SO₄ 90 ppm SiO₂ = 8.4

ppm Mg⁺⁺ 6.8 ppm Na NO₃ = 9.2

APPEARANCE:

Pits: Number None
Depth, mm _____
Diameter at top, mm _____

Color:

Surface roughness-light brown.

CORROSION:

Wt of coat, mg/cm² 0.7 Overall metal lost, 7.5 $\mu\text{g/cm}^2/\text{hr.}$

Corrosion rate, $\mu\text{g/cm}^2/\text{hr.}$ 5.5 (100-300 hrs.)

249-306

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run) Conductivity, reciprocal ohms per cm. 29×10^{-5}

pH <u>7.2</u>	Temp., °C. <u>70</u>
N H ₂ O ₂ <u>1×10^{-5}</u>	Vel., ft./sec. <u>15</u>
ppm Cl ⁻ <u>1.1</u>	Hrs. in test <u>306</u>
ppm Ca ⁺⁺ <u>21</u>	Date finished <u>7-27-44</u>
ppm SO ₄ ⁻ <u>87</u>	ppm SiO ₂ = 8.8
ppm Mg ⁺⁺ <u>6.5</u>	ppm NO ₂ ⁻ = 9.3

APPEARANCE:

Pits: Number None
Depth, mm
Diameter at top, mm
Color: Medium grey-moderate roughness.

CORROSION:

Wt. of coat, mg/cm² .48

Overall metal lost,
µg/cm²/hr. 6.6

Corrosion rate, µg/cm²/hr. 7.25 (100-300 hrs.)

CORROSION TEST RUN

Data - N.B.# 1102 B Page 72

OBJECT:

To determine the corrosion of die cast alloy 360 at the following conditions:

CONDITIONS: -(Average thruout run) Conductivity, reciprocal ohms per cm. 23×10^{-5}

pH <u>7.5</u>	Temp., °C. <u>85</u>
N H_2O_2 <u>1×10^{-5}</u>	Vel., ft./sec. <u>24</u>
ppm Cl^- <u>1.0</u>	Hrs. in test <u>301</u>
ppm Ca^{++} <u>20</u>	Date finished <u>8-22-44</u>
ppm SO_4^{--} <u>75</u>	ppm SiO_2 = 8.5
ppm Mg^{++} <u>6.5</u>	ppm $Na_2Cr_2O_7 \cdot 2H_2O$ = 2.5

APPEARANCE:

Pits: Number None
 Depth, mm
 Diameter at top, mm

Color: Smooth, black. Moderate roughness.

CORROSION:Wt. of coat, mg/cm² 2.4Overall metal lost,
μg/cm²/hr. 21.9Corrosion rate, μg/cm²/hr. 2.19 (0-300 hrs.) ~~SECRET~~

8-49-308

OBJECT:

To determine the corrosion of die cast alloy A360 at the following conditions:
CONDITIONS: -(Average thruout run) Conductivity, reciprocal ohms per cm. 23×10^{-5}

pH 7.8	Temp., °C. 85
N H ₂ O ₂ 1×10^{-5}	Vel., ft./sec. 24
ppm Cl ⁻ 1.0	Hrs. in test 301
ppm Ca ⁺⁺ 20	Date finished 8-22-44
ppm SO ₄ ⁼⁼ 76	ppm SiO ₂ = 8.8
ppm Mg ⁺⁺ 6.5	ppm Na ₂ Cr ₂ O ₇ 2H ₂ O = 2.5

APPEARANCE:

Pits: Number _____
Depth, mm _____
Diameter at top, mm _____

Color: Smooth-black. Moderate roughness.

CORROSION:

Wt. of coat, mg/cm² 1.5

Overall metal lost,
µg/cm²/hr. 13.1

Corrosion rate, µg/cm²/hr. 13.0 (100-300 hrs.)

OBJECT:

To determine the corrosion of 2s Aluminum at the following conditions:

CONDITIONS: -(Average thruout run) Conductivity, reciprocal ohms per cm. 25×10^{-5}

pH 8.1

Temp., °C. 95

N H₂O₂ 1×10^{-5}

Vel., ft./sec. 22 ft./sec.

ppm Cl⁻ 1.0

Hrs. in test 300

ppm Ca⁺⁺ 20

Date finished 8/29/44

ppm SO₄⁼ 73

ppm SiO₂ = 8.2

ppm Mg⁺⁺ 6.5

APPEARANCE:

Pits: Number None

Depth, m.

Diameter at top, mm

Color:

Dark grey--smooth. Mild roughness.

CORROSION:

Wt. of coat, mg/cm² 0.9 Overall metal lost,
µg/cm²/hr. 5.5

Corrosion rate, µg/cm²/hr. 1.95 (100-300 hrs.)

CORROSION TEST RUN

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run) Conductivity, reciprocal ohms per cm. 24×10^{-5}

pH 7.3Temp., °C. 95N H₂O₂ 1×10^{-5} Vel., ft./sec. 22ppm Cl⁻ 1Hrs. in test 300ppm Ca⁺⁺ 19Date finished 8/29/44ppm SO₄⁻ 78ppm NaH₂P₂O₇ 10ppm Mg⁺⁺ 5.8ppm Na₂Cr₂O₇·2H₂O 2.0APPEARANCE:Pits: Number NoneDepth, mm Diameter at top, mm Color:

Light gray--moderately rough.

CORROSION:Wt. of coat, mg/cm² 0.19

Overall metal lost,

.40 (100- 300 hrs. µg/cm²/hr. 0.79)Corrosion rate, µg/cm²/hr. 2.7 (0-50 hrs.)

8-49-311

~~SECRET~~

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:
CONDITIONS: (Average thruout run) Conductivity, reciprocal ohms per cm. 22×10^{-5}

pH 7.4 Temp., °C. 95
N H₂O₂ 1×10^{-5} Vel., ft./sec. 22
ppm Cl⁻ 1.0 Hrs. in test 300
ppm Ca⁺⁺ 21 Date finished 8/29/44
ppm SO₄⁻ 73
ppm Mg⁺⁺ 6.2 ppm Na₂Cr₂O₇·2H₂O = 2
ppm Marathon Limon #365 = 10

APPEARANCE:

Pitts: Number None
Depth, mm _____
Diameter at top, mm _____

Color: Dark grey Mild roughness.

CORROSION:

Wt. of coat, mg/cm² 0.27 Overall metal lost,
µg/cm²/hr. 1.6
Corrosion rate, µg/cm²/hr. 0.11 (100-300 hrs.)

SECRET

S-49-312

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run) Conductivity, reciprocal ohms per cm. 25×10^{-5}

pH <u>7.5</u>	Temp., °C. <u>70</u>
N H ₂ O ₂ <u>1×10^{-5}</u>	Vel., ft./sec. <u>15</u>
ppm Cl ⁻ <u>1.1</u>	Hrs. in test <u>305</u>
ppm Ca ⁺⁺ <u>23</u>	Date finished _____
ppm SO ₄ ⁻ <u>84</u>	SiO ₂ ppm = <u>7.8</u>
ppm Mg ⁺⁺ <u>5.2</u>	NO ₂ ⁻ ppm = <u>2.0</u>

APPEARANCE:

Pits: Number None
 Depth, mm _____
 Diameter at top, mm _____
 Color: moderate
Light grey-brown-- roughness.

CORROSION:

Wt. of coat, mg/cm² 0.34 Overall metal lost, 18.2
 µg/cm²/hr.
 Corrosion rate, µg/cm²/hr. 16.0 (100-300 hrs.)

CORROSION TEST RUN

Data. = N.B.#. 1102 Page 82

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run) Conductivity, reciprocal ohms per cm. 24×10^{-5} pH 7.6Temp., °C. 70N H₂O₂ 1×10^{-5} Vel., ft./sec. 15ppm Cl⁻ 1.1Hrs. in test 305ppm Ca⁺⁺ 23

Date finished _____

ppm SO₄⁼ 80ppm SiO₂ = 7.0ppm Mg⁺⁺ 5.0ppm NO₂ = 4APPEARANCE:Pits: Number None

Depth, mm _____

Diameter at top, mm _____

Color:

Grey-brown, Mild roughness.CORROSION:Wt. of coat, mg/cm² 0.47

Overall metal lost,

μg/cm²/hr. 15.9Corrosion rate, μg/cm²/hr. 14.0 (100-300 hrs.)

CORROSION TEST RUN

Data - N.B. # 1102B Page 8EOBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: - (Average thruout run) Conductivity, reciprocal ohms per cm. 29.5×10^{-5} pH 8.5Temp., °C. 95N H₂O₂ 1.0×10^{-4} Vel., ft./sec. 9ppm Cl⁻ 1.0Hrs. in test 286ppm Ca⁺⁺ 24Date finished 9-6-44ppm SO₄⁼ 90ppm Na₂Cr₂O₇·2H₂O 2.2ppm Mg⁺⁺ 4.1ppm SiO₂ 12.8APPEARANCE:Pits: Number NoneDepth, mm Diameter at top, mm

Color:

Medium gray--moderate general roughness.

CORROSIONWt. of coat, Mg/cm² 0.66Overall metal lost,
μg/cm²/hr. 0.68Corrosion rate, μg/cm²/hr. 1.75 (50-300 hrs.)

CORROSION TEST RUN

Run No. 193Data - N.B.# 1102B Page 89OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: - (Average thruout run)pH 8.0N H₂O₂ 6 x 10⁻⁵ppm Cl⁻ 1ppm Ca⁺⁺ 25ppm SO₄⁼ 84ppm Mg⁺⁺ 3.6Conductivity, reciprocal ohms per cm 26.6 x 10⁻⁵Temp., °C. 95Vel., ft./sec. 9Hrs. in test 201Date finished 9-6-44ppm Na₂H₂P₂O₇ 5.2ppm Na₂Cr₂O₇ · 2H₂O 2.0ppm SiO₂ 6.2APPEARANCE:Pits: Number NoneDepth, mm. Diameter at top, r

Color:

Medium gray--moderate general roughness.

CORROSION:Wt. of coat, Mg/cm² 0.36Overall metal lost,
µg/cm²/hr. 0.14Corrosion rate, µg/cm²/hr. 1.1 (0-300 hrs.)

CORROSION TEST RUN

Run No. 194

Data - N.B.# 1102B Page 90

OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run) Conductivity, reciprocal ohms per cm. 50.3×10^{-5}

pH 8.1

Temp., °C. 95

N H₂O₂ 5×10^{-5}

Vel., ft./sec. 9

ppm Cl⁻ 1.5

Hrs. in test 302

ppm Ca⁺⁺ 23

Date finished 9-6-44

ppm SO₄⁼ 119

ppm Calgon 2.2

ppm Mg⁺⁺ 5.9ppm SiO₂ 7.4ppm Na₂Cr₂O₇·2H₂O 2.2APPEARANCE:

Pits: Number None

Depth, mm

Diameter at top, mm

Color:

Medium gray-- moderate general roughness.

CORROSION:Wt. of coat, Mg/cm² .45Overall metal lost,
µg/cm²/hr. .18Corrosion rate, µg/cm²/hr. 1.3 (100-250 hrs.)

-549-317

CORROSION TEST RUN

Run No. 195Data - N.B.# 1102 B Page# 92OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 6.9Temp., °C. 70N H₂O₂ 2 x 10⁻⁵Vel., ft./sec. 23ppm Cl⁻ 1.1Hrs. in test 351ppm Ca⁺⁺ 21Date finished 9-20-44ppm SO₄⁼ 87ppm Mg⁺⁺ 6.8APPEARANCE:

Pits: Number Few
 Depth, mm .01-.05
 Diameter at top, mm .1-.3

Color:
 Medium gray--moderate roughness.

CORROSION:Wt. of coat, Mg/cm² 0.14Overall metal lost,
μg/cm²/hr. 1.6

Corrosion rate, μg/cm²/hr. .86 (100-350 hrs.)
1.8 (0-100 hrs.)

J-49-318

CORROSION TEST RUN

Run No. 196Data - N.B.# 1102B Page 93OBJECT:

To determine the corrosion of 2S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 6.9Temp., °C. 80N H₂O₂ 5 x 10⁻⁵Vel., ft./sec. 22ppm Cl⁻ 1.4Hrs. in test 351ppm Ca⁺⁺ 22Date finished 9-20-44ppm SO₄⁻ 85ppm Mg⁺⁺ 6.2APPEARANCE:

Pits: Number - Few
Depth, mm - .01-.05
Diameter at top, mm .1-.3

Color:

Moderate roughness - Medium gray.

CORROSION:Wt. of coat, Mg/cm² 0.18Overall metal lost,
µg/cm²/hr. 1.5Corrosion rate, µg/cm²/hr. .86 (150-350 hrs.)
1.5 (0-150 hrs.) ~~SECRET~~

S-49-319

CORROSION TEST RUN

Date - N.B.# 1102B Page 104

OBJECT:

To determine the corrosion of 61ST aluminum at the following conditions:

CONDITIONS: -(Average thruout run)

pH 6.5

Temp., °C. 70

N H₂O₂ 2×10^{-5}

Vel., ft./sec. 9

ppm Cl⁻ 1

Hrs. in test 390

ppm Ca⁺⁺ 0

Date finished 10-9-44

ppm SO₄⁻² 0ppm Mg⁺⁺ 0APPEARANCE:

Pits: Number None

Depth, mm

Diameter at top, mm

Color:

Medium gray. Roughened surface.

CORROSION:Wt. of coat, Mg/cm² 0.36Overall metal lost,
µg/cm²/hr. 1.1Corrosion rate, µg/cm²/hr. 0.03 (100-400 hrs.)
0.33 (0-100 hrs.)

S-49-320

Run No. 198

CORROSION TEST RUN

Date - N.B.# 1102B Page 105

OBJECT:

To determine the corrosion of 61ST aluminum at the following conditions:

CONDITIONS: - (Average thruout run)

pH	6.5	Temp., °C.	35
N H ₂ O ₂	0	Vel., ft./sec.	9
ppm Cl ⁻	1	Hrs. in test	390
ppm Ca ⁺⁺	0	Date finished	10-9-44
ppm SO ₄ ⁼	0		
ppm Mg ⁺⁺	0		

APPEARANCE:

Pits: Number None
 Depth, mm _____
 Diameter at top, mm _____
 Color: Light gray, Moderate roughness.

CORROSION:

Wt. of coat, Mg/cm² 0.10 Overall metal lost,
 µg/cm²/hr. 0.32
 Corrosion rate, µg/cm²/hr. 0.08 (50-400 hrs.)

~~SECRET~~

8-49-321

CORROSION TEST RUN

OBJECT:

To determine the corrosion of 52S aluminum at the following conditions:

CONDITIONS: - (Average thruout run)

pH 6.5

Temp., °C. 70

N H₂O₂ 2 x 10⁻⁵

Vel., ft./sec. 9

ppm Cl⁻ 1

Hrs. in test 390

ppm Ca⁺⁺ 0

Date finished 10-9-44

ppm SO₄⁼ 0ppm Mg⁺⁺ 0APPEARANCE:

Pits: Number None

Depth, mm

Diameter at top, mm

Color:

Dark gray. Roughened surface.

CORROSION:Wt. of coat, Mg/cm² 0.30Overall metal lost,
μg/cm²/hr. 1.8Corrosion rate, μg/cm²/hr. 0.18 (150-400 hrs.)
2.3 (0-150 hrs.)

A-49-322

CORROSIONS TEST RUN

OBJECT:

To determine the corrosion of 525 aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 6.5Temp., °C. 35N H₂O₂ 0Vel., Ft./sec. 9ppm Cl⁻ 1Hrs. in test 390ppm Ca⁺⁺ 0Date finished 10-9-44ppm SO₄⁼ 0ppm Mg⁺⁺ 0APPEARANCE:Pits: Number NoneDepth, mm -Diameter at top, mm -

Color:

Light gray. Roughened surface.

CORROSION:Wt. of coat, Mg/cm² 0.23Overall metal lost,
µg/cm²/hr. 0.79Corrosion rate, µg/cm²/hr. 0.1 (100-400 hrs.)

SECRET

UNCLASSIFIED

1-99-323

Run No. 201

CORROSION TEST RUN

Data - N.B.# 1102B Page 108OBJECT:

To determine the corrosion of 52S aluminum at the following conditions:

CONDITIONS: -(Average thruout run)pH 7.3Temp., °C. 70N H₂O 2 x 10⁻⁵Vel., ft./sec. 9ppm Cl⁻ 1Hrs. in test 390ppm Ca⁺⁺ 0Date finished 10-9-44ppm SO₄ 0ppm Mg⁺⁺ 0APPEARANCE:Pits: Number Depth, mm Diameter at top, mm

Color:

Light gray. Roughened surface.CORROSION:Wt. of coat, Mg/cm² 0.36Overall metal lost,
μg/cm²/hr. 1.0Corrosion rate, μg/cm²/hr. .16 (100-400 hrs.)

S-49-324

-326-

CORROSION TEST RUN

Run No. 202Data - N B # 1102 Page# 113OBJECT:

To determine the corrosion of die cast alloy 360 at the following conditions:

CONDITIONS: - (Average thruout run)pH 6.5Temp., °C. 85N H₂O₂ 2x10⁻⁵Vel., ft./sec. 23ppm Cl⁻ 1Hrs. in test 370ppm Ca⁺⁺ 20Date finished 10-23-44ppm SO₄⁻ 85Special Conditions Noneppm Mg⁺⁺ 6APPEARANCE:

Pits: Number Numerous
 Depth, mm .05-.4
 Diameter at top, mm .5-2

Color:

Black- pits filled with oxide. Numerous barnacles.

Moderate roughness

CORROSION:Wt. of coat, Mg/cm² 5.3Overall metal lost,
ug/cm²/hr. 20.6Corrosion rate, ug/cm²/hr. 5.4 (150-400 hrs.)

UNCLASSIFIED 325

CORROSION TEST

Date - N B. # 1102 B 114

OBJECT:

To determine the corrosion of die cast alloy A-360 at the following conditions:

CONDITIONS: -(Average thruout run)pH 6.5Temp., °C 85N H₂O₂ 2x10⁻⁵Vel., ft./sec. 23ppm Cl⁻ 1Hrs in test 370ppm SO₄ 85Date finished 10-13-44ppm Mg⁺⁺ 6Special Conditions Noneppm Ca⁺⁺ 20APPEARANCE:

Pits: Number Moderate
 Depth, mm .05-.1
 Diameter at top, mm .05-.2

Color: Black Moderate roughness

CORROSION:Weight loss, Mg/cm² 1.0

Overall metal loss,
 µg/cm²/hr 6.3

Corrosion rate, µg/cm²/hr. -6.0(150-400 hrs)