NAS 8-11226

FINAL REPORT

DEVELOPMENT OF IMPROVED CONVERSION COATINGS FOR ALUMINUM ALLOYS

ALCOA

ALCOA RESEARCH LABORATORIES

NEW KENSINGTON, PA.

Contract NAS8-11226
Control No. 1-4-50-01018-01 (1F)
CPB 02-1059-64

DEVELOPMENT OF IMPROVED CONVERSION COATINGS FOR ALUMINUM ALLOYS

Final Report
May 1, 1964-July 31, 1966

W. G. Zelley
W. G. ZELLEY

Alcoa Research Laboratories
Aluminum Company of America
New Kensington, Pennsylvania

September 14, 1966

This report was prepared by the Alcoa Research Laboratories, Aluminum Company of America under Contract NAS8-11226, "Development of Improved Conversion Coatings For Aluminum Alloys", for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of the Propulsion and Vehicle Engineering Laboratory, Materials Division of the George C. Marshall Space Flight Center with Mr. Ralph H. Higgins acting as project manager.

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

Appendix

Index of Tables

Tables 1-76

Index of Figures

Figures 1-77

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

Surface Preparation (cont.)

Contract NAS8-11226

DEVELOPMENT OF IMPROVED CONVERSION COATINGS FOR ALUMINUM ALLOYS

Final Report
May 1, 1964-July 31, 1966

ABSTRACT

An investigation was conducted on the protection of 2219 alloy by chemical conversion coating techniques, with reference to space vehicle components. The corrosion properties of the alloy in various tempers were considered, and the Iridite 14-2 process, now in use, was studied. Other conversion coatings, with and without chromate, were considered. Surface preparatory treatments were investigated, and the advantage of a mechanical finish for producing an effective coating was shown. Electrochemical assists, double coating, and sealing were evaluated. The value of reducing Iridite solution pH or increasing the concentration was demonstrated, and a 10 oz/gal. solution was studied in depth. Production operational problems were considered, including a pilot plant scale test. Salt spray, humidity, and atmospheric exposure tests were conducted on 2219 alloy in various tempers and on other representative aluminum alloys. The exposure and alloy factors affecting results are discussed. Although the objective of a completely protective coating on 2219-T87 alloy in a 168 hours salt spray exposure was not attained, recommendations were made for the optimum processing of this material according to the data accumulated.

OBJECTIVES

The principal objective of Contract NAS8-11226 was to develop an improved chemical conversion coating process to protect 2219-T87 alloy from corrosion. A coating would be considered adequate if it were capable of resisting corrosion for a minimum of 168 hours in the 5% NaCl continuous spray. The concern with respect to corrosion on space vehicle components is the contamination of the system with products of corrosion, rather than the likelihood of a decrease in the structural integrity of the part. Because of the strong oxidizing properties of rocket fuel products, coatings with organic components must, in general, be avoided.

Iridite 14-2 (Allied Research Products, Inc.) was specified as the control conversion coating process for this program. The major effort was to be directed to the -T87 temper, since that has proven to be the more difficult to treat; the -T37 temper has not been especially troublesome. Various surfaces were of interest--mill finish, machined, and chemically milled. Likewise, it was important to determine if surfaces representing the interior of a plate respond the same as the outer regions.

Of secondary importance was the effect of subsequent heating on the corrosion resistance of chemical coatings. Diminished salt spray resistance around welded areas now requires the Iridite coating to be removed for a distance of 12 inches from the weld, and to be re-applied manually. Similarly, the deleterious effect of heating the coating on its salt spray resistance limits the temperature of drying following hydrostatic testing. It would be advantageous for the conversion coating to be less sensitive to elevated temperature.

Although salt spray exposure has been employed as an accelerated test, it is the actual storage environments that will be important on the space vehicles. Therefore, it was deemed necessary to accumulate humidity and atmospheric exposure test data also. Finally, any coating procedure developed for 2219 alloy should function on other commonly used aluminum alloys; durability exposure data were to be accumulated on these as well.

LITERATURE SURVEY

A survey was made of the technical and patent literature on the chemical coating of aluminum alloys, and 115 references in 7 categories were noted. This survey was reported separately at the start of the program. A supplemental list of 12 references was included in the report for the 17th month. The results indicated that while there was considerable information on the general subject of chemical coating of aluminum, there was very little specifically on 2219 alloy. Likewise, no process was disclosed for coating 2219 alloy to meet the salt spray specification (MIL-C-5541). The literature did show the effectiveness of hexavalent chromium as an inhibitor for chloride attack on aluminum, especially on the copper bearing alloys. For that reason, the survey suggested that the amorphous chromate conversion coating, with its high hexavalent chromium content, was the most promising candidate for developing an improved system on 2219 alloy.

MATERIAL

For this program, samples of 2219 alloy were obtained in the -F (as fabricated), -T37 (solution heat treated with 6-10% cold work), and -T87 (solution heat treated, cold worked, and artificially aged) tempers. In addition, -F temper material was converted to -T62 (solution heat treated and aged without cold work) temper, and -T37 temper material was subjected to various aging periods to study the effect of converting to the -T87 temper.

Table 1 shows the chemical analysis of all the lots of 2219 alloy employed in this program, while Table 2 shows the solution potential measurements as well as selected hardness and electrical conductivity measurements. The physical properties of 2219-T87 and 2219-T37 alloys and the effect of artificial aging time on properties and solution potential are summarized in Table 3.

Figures 1, 2, and 3 are photomicrographs at 100X showing the structure of 2219 alloy in the -T37, -T87, and -T62 tempers. In the -T37 temper, Figure 1, most of the copper is in solid solution, providing the grain contrast. The dark specks represent insolubles, while the white specks represent $CuAl_2$ out of solution because of the high copper content of this alloy. Figure 2 shows the -T87 temper with the $CuAl_2$ precipitate from thermal aging. There is less grain contrast as a result of bringing copper out of solution. Again the insolubles are evident as black specks, and the cross-hatch effect is the result of $CuAl_2$ precipitating on slip planes. Figure 3 shows the structure of -T62, which is also an aged temper. Here the contrast is the result of a denser $CuAl_2$ precipitation (larger particles), probably caused by a higher aging temperature. The mechanical properties of 2219-T62 are lower than those of 2219-T87.

Since any coating process specified for use on 2219 alloy must also be capable of handling other aluminum alloys, it would be necessary to conduct some tests on other alloy types. Therefore, the following material was included in the program for comparison purposes:

Aluminum-Copper Alloy	2014-T6
Aluminum-Magnesium Alloy	5052-H38
Aluminum-Magnesium Silicide Alloy	6061-T6
Aluminum-Copper-Magnesium-Zinc Alloy	7075-T6

The identification and chemical analysis of this material is shown in Table 4.

CORROSION STUDIES

Salt Spray Exposure of 2219 Alloy

Because of the reported difference in response between 2219-T37 and 2219-T87, it was desirable to obtain corrosion data on these two tempers. Weight loss and type and depth of attack were obtained, with and without an Iridite coating, after 1, 3, 5, and 7 days in the 5% continuous salt spray. These data are shown in Table 5.

The somewhat greater weight loss with the -T87 temper, and the beneficial effect of the Iridite coating in reducing attack of both tempers are apparent. Depth of attack values were greater with the -T37 temper since the corrosion was intergranular. With the -T87 temper, the type of attack was pitting, and although the depth was less, the total amount of corrosion was greater.

Solution Potential and Electrical Conductivity Measurements

Solution potential and electrical conductivity measurements for the various lots of 2219 alloy were shown previously in Table 2. A comparison of solution potential measurements on 2219 alloy samples with and without an Iridite coating was obtained as follows:

	Uncoated	Iridite Coated
2219-F	802 mv	801 mv
2219-T37	643 mv	632 mv
2219-T87	797 mv	796 mv

The decrease in potential and electrical conductivity values between the -F (as fabricated) and -T37 tempers reflects the increase of copper in solid solution as a result of the thermal treatment. These values increase again between the -T37 and -T87 tempers, because the amount of copper in solid solution has been decreased substantially by the precipitation of $CuAl_2$ on artificial or thermal aging. Since the amount of cold work the metal had received also affects the electrical conductivity, these measurements show the same trend but are not directly comparable to the potential measurements. High matrix potentials and the accompanying large differences between anodic and cathodic areas lead to increased corrosion. The precipitation of $CuAl_2$, which occurs on aging, both increases the matrix potential and furnishes cathode areas.

The similarity of the potential values of the bare and Iridite coated samples indicates that the Iridite coating does not provide a complete barrier against the corrosive media. It would seem, then, that a large portion of its protective properties are a result of the hexavalent chromium content serving as an anodic inhibitor. This is significant in view of the problem of forming an impervious chemical conversion coating of any type on high copper alloys.

Current Flow Measurements

Following the potential measurements, Iridite coated samples of the -T37 and -T87 tempers were coupled to the uncoated samples of the same temper. The current flow was measured, and after 105 minutes these values were as follows:

Uncoated 2219-T37 Coupled to Iridite coated 2219-T37 (Anode)	0.060 milliamp.
Uncoated 2219-T87 Coupled to Iridite coated 2219-T87 (Anode)	0.66 milliamp.

The current flow with the -T87 temper was about ten times that of the -T37 temper, presumably because of the greater number of cathode sites with the former. It was somewhat unexpected to find that the coated sample was the anode, and this may indicate a tendency for Iridite to preferentially cover cathodic areas. In any event, it is apparent that the -T37 temper is inherently less susceptible to corrosion and easier to protect.

Effect of Heating on the Performance of Iridite Coatings

The deleterious effect of heating Iridite coated 2219-T87 alloy on its resistance to salt spray is believed to be caused by an insolubilizing of the film. As a result, the amount of leachable chromate available as an anodic inhibitor in the corrosion reaction becomes limited.

To gain factual data on this aspect, 3" x 6" x 0.125" samples of 2219-T87 alloy were prepared with the following system: a sulfuric acid-chromic acid etch, a sodium hydroxide etch, a sulfuric acid-chromic acid de-smut, and an Iridite 14-2 conversion coating. Thermal treatments of one hour at 130°F, 160°F, and 200°F were then applied to three of the samples. These and an unheated sample were then leached for one hour in 1 liter volumes of distilled water at 180°F. The water samples were analyzed for chromium using a colorimetric technique with diphenyl carbazide. Results obtained on two separate tests with different weight Iridite coatings were as follows:

	Test #1	Test #2
As prepared	0.25 mg Cr	0.34 mg Cr
1 hr. at 130°F	0.21	0.31
1 hr. at 160°F	0.14	0.15
1 hr. at 200°F	0.02	0.03
Distilled Water Blank	0.00	0.00

The decrease in leachable chromate with increasing thermal treatment of the conversion coating is apparent. In Test No. 2 the Iridite coating was thicker and consequently had a higher total chromate content. This was reflected in the leach analysis on samples in the "as prepared" condition and those heated at 130°F. However, higher temperatures apparently insolubilized the coatings to the extent that the leached values for the two samples were comparable and low. The results of this test are in agreement with the hypothesis that the effect of temperature on corrosion resistance is related directly to the solubility of the chromate content of the coating.

Effect of Storage on the Performance of Iridite Coatings

There has been some speculation as to the effect of room temperature storage of Iridite coated 2219 alloy on its subsequent salt spray resistance. It is known that chromate conversion coatings on aluminum, after standing for a few hours, become insoluble even in strong acids. This raises the question as to whether this obviously more inert coating has any greater salt spray resistance. On the other hand, it was demonstrated above that heating an Iridite coating renders the hexavalent chromium content less soluble and decreases the corrosion resistance by the reduction of available anodic inhibitor. Nautral aging could have the same type of effect.

To evaluate this aspect of salt spray performance, a test was started to compare the relative corrosion of Iridite coated 2219-T87 alloy panels which had aged for 4, 3, 2, and 1 weeks and for 24 hours and 2 hours prior to exposure. The 2 hours represents the shortest interval of time that could be arranged between sample preparation and entry to the salt spray cabinet. All samples were taken from the same lot of metal, and all coatings were applied from Iridite solutions reserved for this use only. The Iridite solutions were a conventional bath (1.25 oz/gal. at pH 1.5) and a 1.25 oz/gal. acidified to pH 0.9 to render it more active. Coatings were applied for 3 minutes at 85°F. Starting 4 weeks prior to the scheduled exposure period, samples of 2219-T87 alloy were chemically cleaned and coated at the specified intervals and stored in an office atmosphere at ambient temperature. Upon completion of the 4 weeks preparation and storage period, all the samples were exposed together to the 5% NaCl continuous spray for 168 hours.

Table 6 summarizes these samples and the corrosion results obtained. Significantly, those samples which had been exposed within 2 hours of preparation showed almost no corrosion in the 168 hour test and were among the best obtained on 2219 alloy. With the pH 1.5 Iridite samples, 24-hours storage was sufficient to produce noticeable corrosion, and the normal amount of attack was observed with 1 week and longer storage. The pH 0.9 solution, with its heavier coating formation, showed to advantage in that only mild corrosion was encountered with 1 day to 2 weeks storage, and attack comparable to the above pH 1.5 samples did not appear until after 3 weeks storage.

THE IRIDITE 14 PROCESS

Iridite 14-2 (Allied Research Products, Inc., Baltimore, Md.) is the chromate conversion coating process currently used on 2219 alloy space vehicle parts. It was specified as the control process for this program and accordingly was examined first.

An examination of the patent literature indicated that U.S. 2,796,370 and 2,796,371 issued on June 18, 1957, to Ostrander, Congiundi, and Pocock are the basic patents for the Iridite 14-2 process. These patents claim a chemical conversion coating composition consisting of a hexavalent chromium compound, a fluorine bearing compound, a soluble cyanide from the group of ferrocyanides and ferricyanides, and a water soluble source of barium.

Analyses

A sample of the Iridite 14-2 powder used in this program was ashed at 500°C and analyzed spectrographically. The results of this analysis are shown in Table 7. A wet analysis indicated that Iridite powder might average about 30% hexavalent chromium and 5% fluoride. An example from the above patents, which represents a typical operating bath composition is as follows:

5.0 g/l CrO_3
1.0 g/l $K_3Fe(CN)_6$
1.9 g/l $Ba(NO_3)_2$
1.35 g/l Na_2SiF_6
pH 1.5

Iridite coatings applied to 2219 alloy were analyzed in the electron microprobe, which is sensitive to elements with atomic numbers greater than 12. After corrections were made for the effect of the substrate, the following average values were obtained for the coating:

Chromium	39%
Aluminum	7%
Iron	3.6%

Copper, although an important component of the substrate, did not appear to be a significant part of the coating.

Since a substantial quantity of iron was found in the coating, it became of interest to know whether it was still in the ferricyanide form or whether this compound had been decomposed. Therefore, conversion coatings were prepared from chromate-fluoride baths, with and without the ferricyanide component; and these coatings were subjected to an infrared spectrographic analysis. This analysis showed a positive identification of the cyanide radical, $-C{\equiv}N$, and chromate on the surface of the sample treated in the ferricyanide containing solution. The sample from the non-ferricyanide solution showed only the presence of a chromate. Consequently, it appears that the ferricyanide radical, used as the "accelerator" in the Iridite bath, is incorporated in the film without decomposition.

As a result of the above analyses, it was speculated that the Iridite film consisted of alumina and chromium chromates and chromium ferricyanide.

Effect of Solution Components on Iridite Coating Weight

The potassium ferricyanide component of the Iridite conversion coating solution is frequently referred to as an "accelerator". This suggests that it catalyzes or accelerates the coating formation. A comparison of a chromic acid-sodium silicofluoride solution, with and without 1 g/l of potassium ferricyanide showed an increase in coating weight from 9 to 20 mg/sq.ft. when the ferricyanide was employed. The above analytical data, however, indicate that the ferricyanide actually becomes a part of the conversion film, rather than merely accelerating its formation. It is of further interest to note that the pH of the conversion coating solution, which is an important variable in the control of the Iridite bath, loses much of its significance if the composition does not include ferricyanide.

The effect of varying the fluoride content of the bath was demonstrated by preparing a solution of 5 g/l CrO_3, 1 g/l $K_3Fe(CN)_6$, and varying amounts of Na_2SiF_6. Samples of mill finish 2219-T87 alloy were etched in hot H_2SO_4-CrO_3, hot NaOH, and hot H_2SO_4-CrO_3 and coated in the above solutions for 3 minutes at 85°F. The coating weight increased with increasing Na_2SiF_6 content, as shown in Figure 4.

When ferricyanide is present in the coating solution, pH, as regulated by nitric acid additions, affects the coating weight markedly. This was demonstrated in the synthesized solution of 5 g/l CrO_3, 1 g/l $K_3Fe(CN)_6$ and 1.35 g/l Na_2SiF_6, using etched 2219-T87 alloy surfaces. A 3 minute coating treatment at 85°F was employed, and the initial pH of 1.5 was reduced with HNO_3 to values of 1.2, 0.9, 0.7, and 0.6. The results are shown in Figure 5.

Additions of HNO_3 to the commercial Iridite solution produced a similar decrease in pH and increase in coating weight. All acids do not respond the same as HNO_3, however. For example, HCl tended to produce excessive activity, while H_3PO_4 had a definite inhibiting effect. When Iridite baths adjusted with HNO_3 were used to coat 2219 alloy samples that had been prepared with various chemical etching treatments, it appeared that bath pH was the dominant factor in determining the coating weight.

Effect of Operating Conditions on Iridite Coating Weight

It was of interest to determine what effect Iridite concentration, time, and temperature would have on the conversion coating weight, when an optimum surface preparation was employed. Therefore, samples of 2219-T87 alloy were prepared for studying these variables by machining the surface and solvent cleaning. Solution concentrations of 1, 1.25, 2, and 3 oz/gal., times of 1, 2, 3, and 6 minutes, and temperatures of 70, 85, and 100°F were evaluated in this test.

At 85°F, using a one or two minute immersion, the Iridite coating weight increased directly with bath concentration. With longer immersions, the coating tended to become powdery and non-adherent. Consequently, each immersion time had a specific bath concentration for maximum adherent coating formation. When the operating temperature was higher than 85°F, the coating weight maximums were encountered at lower concentrations for a given immersion time. At lower temperatures, the reverse trend was observed. Figure 6 shows the effect of concentration at 85°F with various treatment times.

Similarly, at a bath concentration of 1 oz/gal. and a temperature of 85°F, the coating weight increased with increasing immersion time through the 6 minutes evaluated. With increasing concentrations, maximum adherent coatings were obtained at times less than 6 minutes, depending on the concentration. Higher operating temperatures further limit the immersion time range that can be utilized, while lower temperatures extend it. Figure 7 shows the effect of time at 85°F with various concentrations.

Finally, an increase in the operating temperature produced a slight increase in coating weight in a 1 oz/gal. solution employed for 3 minutes. With more concentrated solutions, an increase in the operating temperature had an adverse effect on the coating, causing it to become powdery. Such deleterious results with increasing temperature were greater with longer immersion times and less with shorter. Figure 8 shows the effect of temperature with a 3 minute immersion at three concentrations.

The various data described above suggested that increasing the Iridite bath concentration, decreasing the operating temperature, or decreasing the bath pH, individually or in combination, might yield improved salt spray resistance. Therefore, coatings were applied under these different conditions and tested in the 5% NaCl continuous spray.

In general, it was found that a 3 oz/gal. solution, regardless of the pH or temperature at which it was employed, was not especially advantageous over the 1.25 oz/gal. control. On the other hand, the 6 oz/gal. solution did show some improvement, both at 70°F and 85°F. Since machined surfaces were inherently more active than etched surfaces in Iridite solutions, the lower temperature of 70°F represented a desirable condition for work involving machined as well as mill finish aluminum. Results comparable to those from the 6 oz/gal. solution at 70°F were also obtained from a 1.25 oz/gal. bath, by adjusting the pH to 0.9 with nitric acid.

OTHER CHROMATE CONVERSION COATINGS

The prevalent chromate conversion coating process in use today is the ferricyanide accelerated type, which in addition to Iridite 14-2 is exemplified by such other products as Alodine 1200 (Amchem Products, Inc.) and Bonderite 721 (Parker Rust Proof Co.). All products of this general type would be expected to perform similarly on 2219 alloy.

There are, however, chromate coating processes with different accelerators, and their performance for this application would also be of interest. One such process is that described by Pimbley in U.S. Patent 2,066,055, with nickel ions as the accelerator. Other processes are Bonderite 711 of the Parker Rust Proof Co. and Chem-Rite A22 of M and T Chemicals, Inc. Both of these employ tungstate as an accelerator.

Salt spray testing was conducted on 2219-T87 alloy coated with these processes using other accelerators, in comparison with Iridite 14-2 as a control. No advantage was observed for any of these treatments over the currently used Iridite. Therefore, they were not considered further in this program.

OTHER CONVERSION COATINGS

Conversion coatings other than the chromate type were also evaluated for use on 2219 alloy. One of these was the chromic phosphate type, as represented by Alodine 401 (Amchem Products, Inc.). This also is an acid coating treatment depending on fluoride as the active agent, and it is well established as a preparation for organic coating.

An alkaline coating treatment would be typified by the MBV and Alrok processes. These employ hot sodium carbonate-sodium chromate solutions and form films of aluminum oxide with small amounts of chromic oxide.

Finally, there are the boehmite films formed with boiling water treatments. These films are crystalline, with a typical alpha-alumina-monohydrate structure. A commercial treatment which forms films that might be considered in this general category is the Chemidize Process of the Hughson Chemical Co.

All of these were tried on 2219-T87 alloy and exposed to the 5% continuous salt spray. None was as effective on this alloy as Iridite 14-2, although all showed their best performance when followed with some form of hexavalent chromium sealing treatment. Because they were less effective than Iridite in the salt spray evaluation, they were not considered further for this evaluation.

SURFACE PREPARATION

Effect of Various Treatments

Several different types of surface preparation were evaluated on 2219-T87 alloy samples prior to the application of a 3 minute Iridite 14-2 coating. Coating weight data, obtained by weighing, stripping promptly in nitric acid, and re-weighing, are shown in Table 8. Item No. 1, involving only solvent cleaning on a mill finish surface, showed a relatively modest Iridite coating weight of 24.5 mg/sq.ft. When the thermally formed oxide film was removed by machining or abrading with a Scotch-Brite brush, an Iridite coating of 60-70 mg/sq.ft. was obtained, as shown for Items 4 and 6. Optimum results with Scotch-Brite were obtained when the work was immersed in the Iridite bath without delay. The marked increase in coating weight with Items 4 and 6 appear to demonstrate the value of removing surface oxide prior to Iriditing.

When a chemical deoxidizing treatment was employed, however, some unusual results were obtained. For example, the chemical treatment employed on Item 2 is considered to be very effective for removing oxide, especially thermally formed films. Despite this effective oxide removal, the surface yielded a light Iridite coating. Similar results were obtained on Item 3, using nitric acid as the last immersion. As a further test, the chemical treatment used for deoxidizing was employed following either machining or Scotch-Briting. Here, the previously obtained heavy coatings decreased to low values, as shown for Items 5 and 7.

These results indicate that for effective Iridite coating formation it is important to remove surface oxide without introducing another factor. It would seem that this additional factor must involve either the formation of a thin passive film on the cleaned surface, or less likely, a purging from the surface of constituents that could contribute to conversion coating formation through cell action. The effect encountered here on 2219 alloy is not observed on commercially pure aluminum.

One technique that has been employed for the evaluation of passive films on aluminum surfaces is contact resistance measurements. These are obtained with a Kelvin Bridge, using 1/2 inch diameter copper electrodes at 1000 pounds pressure, with the sample panel interposed between the electrodes. Current and potential leads are connected to each electrode, with the potential lead being as close as conveniently possible to the electrode-aluminum interface. This equipment is illustrated in Figure 9. Resistance measurements for several pretreatments on 2219-T87 alloy are shown in Table 9, immediately and after 1, 3, and 7 days exposure to the laboratory atmosphere. Each value represents the average of 3 readings. Inasmuch as this work was done during warm, humid weather, conditions were conducive to re-growth of the natural oxide film. Indeed, the aluminum surface was sufficiently active after the Scotch-Brite oxide removal treatment that considerable growth occurred even before the measurement could be taken. Chemical deoxidizing treatments, however, deposit residual thin passivating films that inhibit natural oxide growth. Such films are very useful on aluminum when it is desired to maintain a low resistance surface for an application like spot welding. However, it appears that these films also inhibit the action of the Iridite coating solution on 2219 alloy.

Evaluation of Oxide Removal Treatments

A number of etching solutions were evaluated on mill finish 2219-T87 alloy for their effect on Iridite film formation. The use of a single H_2SO_4-CrO_3 etch instead of the previously employed H_2SO_4-CrO_3--NaOH--H_2SO_4-CrO_3 combination resulted in a heavier conversion coating. Coating weights which approached but did not equal that formed on a machined surface were obtained with a room temperature HNO_3-HF treatment and with a hot H_2SO_4-HNO_3 treatment. Smut formation was still a problem with these acid etching solutions, but a room temperature nitric acid immersion removed the smut with only a slight reduction in the subsequent conversion coating weight. Caustic etching was found to increase the Iridite coating weight, if the etching smut were removed by wiping. However, when a nitric acid de-smutting treatment was employed, the surface was again passivated, and a low coating weight resulted. The most complete surface passivation was obtained with the hot H_3PO_4-CrO_3 solution used for stripping anodic coatings from aluminum. Almost no Iridite coating was formed when this was used as the pretreatment. Although a solvent cleaned machined surface produces a heavy Iridite coating, the application of a chemical treatment after machining gives about the same results as on a mill finish surface. Table 10 summarizes these data.

Since a 30 second immersion in 50% nitric acid at room temperature, following the hot sulfuric acid-chromic acid etch, served to remove smut and improve the conversion coating, nitric acid solutions of higher concentration, higher temperature, and longer immersion time were also evaluated. Subsequent salt spray testing, however, revealed no advantage to increasing the nitric acid treatment. This salt spray testing did substantiate, however, that better and more consistent corrosion resistance was obtained on 2219 alloy when the residual film was removed by a room temperature immersion in 50% nitric acid.

Mechanical vs Chemical Preparation

The promising results obtained on machined surfaces of 2219-T87 alloy, warranted making some direct comparisons between chemical and mechanical pretreatments. Therefore, 2219-T87 alloy panels were prepared with hot sulfuric acid or sulfuric acid-chromic acid etching on one hand and Scotch-Brite brushing or liquid-hone blasting on the other. Coatings were applied by a 3 minute immersion at 85°F in 1.25 oz/gal. Iridite solution, both at the normal pH of 1.5 and also at the reduced pH of 0.9. After exposure to the 5% NaCl continuous spray at 95°F for 168 hours, it was apparent that the two samples using mechanical pretreatment were definitely better than those two using chemical pretreatments.

Inasmuch as production parts in the space program might include chemically milled, machined, and mill finish surfaces on the same unit, it was considered desirable to expand the above work on surface preparation into a more comprehensive test. Therefore, 2219-T87 alloy panels were prepared by chemical milling to remove 0.060", by mechanical machining to remove 0.010-0.015", and by Scotch-Brite brushing with very little metal removal. All of these surfaces were then treated with an inhibited alkaline cleaner immediately prior to conversion coating. For comparison, mill finish surfaces were cleaned, etched in either sulfuric acid or sulfuric acid-chromic acid, and de-smutted in nitric acid prior to applying the chemical conversion coating.

Four different conversion coating conditions were employed in this test; namely, 1.25 oz/gal. Iridite at 85°F and pH 1.5, the same solution adjusted to pH 0.9, 6 oz/gal. Iridite at 70°F, and Bonderite 711 at 130°F. The coating time was 3 minutes in all cases. All samples were then exposed to the 5% NaCl continuous spray, this time for the somewhat longer period of 260 hours.

Machining, as usual, produced excellent results with the Iridite coatings, showing very mild to no corrosion in the 260 hour exposure. There would seem to be little, if any, problem if only machined surfaces were involved. The chemically milled surfaces, on the other hand, produced the poorest results in this particular test, even though they had received an hour of vigorous etching followed by an effective de-smutting step. Finally, Scotch-Brite brushing prior to Iridite coating produced a salt spray performance comparable to machining. The acid etched mill finish samples included for comparison were better than those that had been chemically milled, but they were not as good as those that had been machined.

Abrasive Blasting

Since mechanical treatments such as machining and Scotch-Brite brushing had shown to advantage as a preparation for Iridite coating, it was speculated that dry blasting processes might be suitable for preparing the 2219 alloy surface, especially for "touch-up" work. It seemed to be important that the abrasive not be imbedded in the aluminum, since this would require a subsequent etching cleaner which would negate the mechanical finish.

Walnut shells and ground corn cobs, in several grit sizes, were tried first, using a portable blasting unit and 95 pounds air pressure. None of these abrasives were sufficiently aggressive to remove the thermal film from 2219-T87 alloy, nor did they produce outstanding results when the thermal film was first removed chemically.

It was then decided to try glass bead abrasive blasting. The material employed for this was "Glas-Shot" produced by Microbeads Division, Cataphote Corporation, Jackson, Mississippi. Glas-Shot is available in various sizes, and both coarse (-35 plus 60) and fine (-200 plus 325) were tried. The coarse material did not remove the thermal film from 2219-T87 alloy, but the fine material did. To obtain an evaluation of the coarse material as a preparation for Iridite coating, it was necessary first to remove the thermal film chemically.

A salt spray test was prepared in which chemical cleaning, chemical cleaning plus coarse glass blasting, and no cleaning plus fine glass blasting were used prior to Iriditing. Chemical cleaning consisted of a 3 minute inhibited alkaline cleaner at 180°F, a 3 minute H_2SO_4-CrO_3 etch at 180°F, and a 30 seconds 50% HNO_3 de-smut at room temperature. Blasted surfaces were subsequently cleaned in the inhibited cleaner. Iridite coatings were applied for 3 minutes at 85°F in a 1.25 oz/gal. solution at pH 1.5. Duplicate samples were exposed to the 5% NaCl continuous spray at 95°F for 168 hours.

Table 11 summarizes these samples, showing coating weights and corrosion results. Improved salt spray resistance was observed only with the samples prepared by blasting with the fine glass beads (-200 plus 325). This treatment appears to be comparable to the Scotch-Brite brushing described above.

Aging - Machining Sequence

The fact that a machined surface responds to the Iridite coating solution better than an etched surface raises the question of sequence of machining and thermal aging operations. A 2219 alloy surface that is machined while in the -T37 temper and then artificially aged to -T87 might not respond the same as a surface that is machined when in the -T87 temper. To determine this, representative samples of both were Iridite coated and exposed to the 5% NaCl continuous spray for 168 hours. It was shown that when thermal aging followed rather than preceded machining, the Iridite conversion coating was less resistant to salt spray corrosion. Therefore, whenever possible, it would be desirable to schedule production machining operations after the material has been taken to its final temper.

Treatment of Chemically Milled Surfaces

Salt spray tests have shown that a chemically milled surface consistently produced a less resistant Iridite coating than a machined surface, and sometimes even than a mill finish surface. Furthermore, the lower level of performance of the chemically milled surface to the machined surface appears to be independent of how much or how little metal is chemically removed from the 2219 alloy.

Since chemical milling would probably occur at a different location and time than the conversion coating, the question of additional cleaning arises. Salt spray results indicated that a simple inhibited cleaning treatment was preferable to an acid etching treatment.

The previously demonstrated effectiveness of the Scotch-Brite treatment prior to Iridite coating appeared worthy of consideration on a chemically milled surface. Accordingly, samples were prepared and evaluated in the 5% NaCl continuous spray. It was shown that the application of Scotch-Brite to the chemically milled surface produced a definite improvement in the protective properties of the subsequent Iridite coating. This effect was similar to that obtained with Scotch-Brite treatment of a mill finish surface.

ELECTROCHEMICAL ASSISTS

Potential and Current Measurements on 2219 Alloy Couples

In view of the possibility that the galvanic coupling of 2219-T87 alloy to other metals might improve the protective properties of the Iridite coating, several coupling materials were selected for potential and current flow measurements. Open circuit and couple potential readings are shown in Table 12 for 99.99% aluminum, stainless steel, copper, and graphite.

Aluminum galvanically coupled to another material in an electrolyte tends to function as a cell and generate current, to an extent depending on the other electrode and the polarization effects that may occur. Since the couple is functioning as a battery, the electrical energy generated is in the reverse polarity from what would be applied if it were desired to drive the anode-cathode reactions from an external power supply.

The open circuit potentials were similar for the 2219-T87 and 99.99% aluminum samples and substantially different and of opposite polarity for stainless steel, copper, and graphite. Both the stainless steel and the copper showed a polarization effect as a result of being coupled to 2219-T87 for a 3 minute period, while the graphite did not. The coupled potentials showed no deviation from 2219-T87 with the stainless steel, a measurable difference of the same polarity with the copper, and markedly different, opposite polarity results with the graphite.

Current flow values, in milliamperes per square inch, over the 3 minute coating interval are shown for the above couples in Table 13. Figure 10 compares the data graphically. At the end of 3 minutes, the current density is very low with stainless steel, has decreased substantially with copper, but still remains at a relatively high level with the graphite.

The electrode reactions have been further described by diagraming the potential-current values after the 3 minute interval for 2219-T87, stainless steel, copper, and graphite--both open circuit and in couples. These are shown in Figure 11. It is apparent from this graphical representation of the data that, electrochemically, the Iridite coating reaction is dominated by the aluminum anode when the 2219-T87 is coupled to stainless steel or copper. On the other hand, a marked cathodic effect is observed with the graphite. It then becomes necessary to determine whether in either case there is sufficient current flow to noticeably affect the chemical conversion coating reaction.

Salt Spray Samples Prepared by Coupling

Duplicate samples of 2219-T87 alloy were cleaned in an inhibited alkaline cleaner, deoxidized in sulfuric acid-chromic acid, de-smutted in nitric acid, and coated for 3 minutes in 1.25 oz/gal. Iridite 14-2, pH 1.5, 85°F--with and without coupling to 99.99% aluminum, stainless steel, copper, and graphite. After exposure to the 5% NaCl spray for 168 hours, all samples showed corrosion, but the 2219-T87-stainless and 2219-T87-copper couples did seem to be slightly better than the others. It is concluded, therefore, that insufficient current is generated by the galvanic couple to appreciably affect the chemical conversion coating. If an improvement is to be obtained electrochemically, it will seemingly require a greater magnitude of current, such as can be obtained by external application.

Electrolytic Treatments

As a continuation of the galvanic couple experiments conducted above, low voltage anodic and cathodic currents were imposed on 2219 alloy in the Iridite coating solution. An anodic voltage of 3.0 resulted in gassing, while a cathodic voltage of 3.0 was sufficient to partially inhibit coating formation. Salt spray testing showed that an increasing anodic voltage produced a definite degradation in the protective properties of the coating, while cathodic treatments seemed to have no effect. Therefore, it appears that an electrochemical assist will not markedly improve the performance of an Iridite coating on 2219 alloy.

CONCENTRATED IRIDITE SOLUTIONS

Concentration and Operating Conditions

As a result of data obtained during the first year of this contract, the Propulsion and Vehicle Engineering Laboratory at Marshall Space Flight Center tested and expressed an interest in heavier Iridite coatings from more concentrated solutions. Further work in this direction seemed to be of merit.

Therefore, a comparison was made on chemically cleaned 2219-T87 alloy of Iridite coatings produced in a 6 oz/gal. solution at 70, 85, and 100°F and in a 10 oz/gal. solution at 70 and 85°F. Although high concentration solutions tend to produce surface chalking, a substantial layer of sound coating was obtained in each instance. These samples were exposed to the 5% NaCl continuous spray for a total period of 336 hours. At the end of the 336 hours, corrosion was severe on the 6 oz/gal. at 70°F sample and moderate on the others. Of these, the 10 oz/gal. treatments seemed to be slightly better.

This was sufficiently encouraging, especially in view of the 336 hours exposure, to warrant a more extensive investigation of the 10 oz/gal. solution. Since a 10 oz/gal. solution does have a high activity and since it is desirable to have a minimum of surface powdering, it was felt that operating temperatures of 50°F and 70°F held the most promise. Admittedly, this also introduced the aspect of cooling facilities for the Iridite solution.

Duplicate samples of 2219-T87 alloy were alkaline cleaned, etched in hot H_2SO_4-CrO_3, de-smutted in HNO_3, and coated for 3, 4, and 6 minutes in a 10 oz/gal. Iridite solution at 70°F and a 10 oz/gal. Iridite solution at 50°F. For control purposes, similar samples were prepared with a 3 minute coating in a 1.25 oz/gal. Iridite solution at 85°F. These samples were then exposed to the 5% NaCl continuous spray at 95°F, with one sample of each item scheduled for removal after 168 hours and the second after 336 hours.

Table 14 summarizes the 168 hour exposure and shows the coating weights obtained. At this point, the 10 oz/gal. samples were definitely better than the 1.25 oz/gal. control, with the 50°F operating temperature showing a slight advantage. After 336 hours, best results were observed on the 3 and 4 minute coatings at 50°F and then on the 4 and 6 minute coatings at 70°F. Although complete corrosion protection was not obtained by this approach, the performance of these samples in a 336 hours exposure justified further evaluation. Based on the above data, the most promising conditions for additional testing appeared to be 10 oz/gal. at 50°F for 4 minutes. However, some further work was also conducted at 70°F to verify the relative advantage of decreasing the temperature to 50°F. The results of this indicated that the improvement to be gained by operating at 50°F was too slight to warrant maintaining an additional 20° lower temperature. Therefore, the coating treatment recommended was 10 oz/gal. Iridite 14-2 at 70°F for 3 minutes.

Effect of Components in Concentrated Iridite Solutions

The use of a 10 oz/gal. concentration automatically increased by 8 times the amount of each component in the Iridite coating solution. This raised the question as to whether any of the components were more important than others in obtaining improved results.

A preliminary screening indicated that increasing the CrO_3 content or the Na_2SiF_6 content increased the coating weight somewhat but did not appreciably improve the corrosion resistance. Increasing both of these components together tended to produce powdery coatings unless the ferricyanide content was also increased, although increasing the latter alone had no substantial effect. Therefore, the improved results from a 10 oz/gal. solution depends on an increase in concentration of all three major components--CrO_3, Na_2SiF_6, and $K_3Fe(CN)_6$--although the importance of the auxiliary component, $Ba(NO_3)_2$, is questionable. These factors were substantiated on 2219-T87 alloy, S-298772, as shown in Table 15.

Effect of Chromic Acid Additions

Since increasing the Iridite concentration to 10 oz/gal. provided a higher level of corrosion resistance, it was thought of value to explore the effect of making chromic acid additions to this solution. Therefore, some preliminary tests were conducted with 10 oz/gal. Iridite plus 2.5% and 5.0% CrO_3 (25 and 50 g/l).

It was observed that with a well-used Iridite solution the addition of CrO_3 had the effect of markedly inhibiting coating formation. Thus the coating weight for a 3 minute treatment at 70°F was reduced to less than 10 mg/ft^2, and resistance to the 5% salt spray was very poor. The reason for this inhibition was not immediately evident.

On the other hand, such additions to a fresh Iridite solution provided a noticeable increase in color and in coating weight. However, despite a greater coating weight and perhaps an increased amount of hexavalent chromium, no improvement was observed in salt spray performance on 2219-T87 alloy over a 10 oz/gal. coating without additions.

Effect of Storage

Previous data on one lot of 2219-T87 alloy (S-298782) coated in 1.25 oz/gal. Iridite solutions indicated that the salt spray resistance after coating decreased with increasing storage time between coating application and exposure. Thus, excellent results were obtained when the samples were exposed within two hours after preparation, while the normal amount of corrosion was observed when this interval was one week or more.

An effort was now made to relate the above differential performance to heavier coatings formed from concentrated Iridite solutions. Since the leachable hexavalent chromium content appears to be the controlling factor in the salt spray performance of various Iridite coatings, a leaching test was conducted. The test consisted of immersing panels with different storage intervals in distilled water at 95°F for a 24 hour period. The panels were then subjected to two additional 24 hour immersions, using fresh water each time. All samples were then analyzed for hexavalent chromium, and the results are shown in Table 16.

These analytical data indicated the following:

1. The Cr^{+6} content of the first leach increased with decreasing storage time prior to exposure.
2. Increasing the coating weight through a more active coating solution increased the leachable Cr^{+6} content.
3. Only the 10 oz/gal. Iridite treatment showed much tendency toward a controlled release of Cr^{+6} with increased aging time.

Figures 12, 13, and 14 illustrate these results graphically.

Salt Spray Corrosion Progression

Most of the salt spray exposures in this program have been conducted for an uninterrupted 168 hours, for the objective was to obtain resistance over this interval. Since the available hexavalent chromium content has been an important factor in salt spray performance, it seemed of value to follow the progression of corrosion from that point of view.

Fourteen 2219-T87 alloy panels (S-298772) were inhibited alkaline cleaned, etched in hot sulfuric acid-chromic acid, desmutted in nitric acid, and coated for 3 minutes in 10 oz/gal. Iridite 14-2 at 70°F. Each panel was then measured for degree of yellowness (from chromate) on a Color-Eye instrument (Instrument Development Laboratories, Inc., Attleboro, Mass.) and also weighed on an analytical balance. All panels were exposed to the 5% NaCl spray, and two were removed each day through the normal 7 days exposure interval. Evaluation was then conducted on the basis of appearance, change in yellowness, and corrosion weight loss.

After testing, the exposed surfaces of the various panels were again measured for degree of yellowness. These surfaces had obviously undergone a progressive leaching of the hexavalent chromium content, although the back surfaces still retained most of the original color. Table 17 shows the per cent change in yellowness, as determined by the Color-Eye, for each exposure interval. The high initial leaching followed by a more controlled release throughout the remainder of the 168 hours is apparent.

Corrosion weight losses are frequently measured on weighed aluminum samples by removing the corrosion product in concentrated nitric acid and re-weighing. Since it is known that an Iridite coating becomes very insoluble on standing, it was believed possible to employ that technique here. The coating did prove to be insoluble on the backs of the panels; however, surfaces exposed to the salt spray, especially for 2 days or more, exhibited what appeared to be considerable loss of coating. Table 18 shows the weight losses obtained after the second weighing. It is believed that they give a good relative indication of the progression of corrosion, although because of the above described coating solubility, all values are greater than the actual corrosion losses. Figure 15 is a graphical representation of the change in degree of yellowness and the weight loss data.

An overall consideration of the data from this test supports the improved results generally observed with the 10 oz/gal. Iridite coating. This coating has a greater initial hexavalent chromium content and is able to continue to release it over a longer period of time. The rate of corrosion accordingly proceeds at a lower rate with the 10 oz/gal. than with the 1.25 oz/gal. coating. For a specified test interval, then, the concentrated solution can provide improved corrosion resistance. This does not mean, however, that a 10 oz/gal. coating will not show a comparable degree of attack, given a sufficiently extended exposure period.

Effect of Deoxidizing Treatments

Although deoxidizing treatments were discussed rather thoroughly in the Surface Preparation section, they have not, except for hot sulfuric acid-chromic acid, been evaluated in combination with a 10 oz/gal. coating.

Accordingly, an exposure test was prepared using a 10 oz/gal. Iridite solution and the following deoxidizers:

a. 100 ml/l 96% H_2SO_4, 35 g/l CrO_3; 180°F; 3 minutes.

b. 100 ml/l 70% HNO_3, 22.5 g/l $Na_2Cr_2O_7 \cdot 2H_2O$, 2.5 g/l NH_4HF_2; 80°F; 30 minutes.

c. 100 ml/l 96% H_2SO_4, 50 ml/l 70% HNO_3; 150°F, 3 minutes.

d. 100 ml/l 70% HNO_3, 10 ml/l 48% HF; 80°F; 3 minutes.

e. 3M Scotchbrite.

Duplicate panels of 2219-T87 alloy (S-298772) were inhibited alkaline cleaned, deoxidized as above, and except for Scotchbrite, de-smutted in room temperature nitric acid. A 3 minute Iridite coating was applied from a 10 oz/gal. solution at 70°F. For comparison, a 1.25 oz/gal. coating was applied over the usual H_2SO_4-CrO_3 etched surface. All panels were then exposed to the 5% NaCl continuous spray for 168 hours. The samples and the corrosion results are summarized in Table 19.

Best results were observed with the Scotchbrite finish, but there was little difference among the chemically deoxidized samples. Apparently, any of the chemical treatments could be adapted satisfactorily to the concentrated Iridite bath. On the other hand, if Scotchbrite were to be used without subsequent chemical etching, it would probably be beneficial to reduce either time or temperature of the 10 oz/gal. coating operation.

Effect of Artificial Aging to -T87 Temper

Since it had been established previously that 2219 alloy in the -T37 temper performed better in the salt spray than in the -T87 temper, when Iridite coated, it was of interest to determine the effect of variability in aging.

Accordingly, samples of 2219-T37 were subjected to thermal treatment at 325°F for various times. A period of 24 hours at this temperature should produce satisfactory aging to -T87, and time intervals substantially lower and higher than this were included to provide a range. Solution potential measurements were obtained on each item as an indication of the degree of precipitation of copper from solid solution. These results are shown in Table 3 (S-298779).

The above items were then cleaned in the usual manner and coated in 1.25 oz/gal. Iridite for 3 minutes at 85°F and in 10 oz/gal. Iridite for 3 minutes at 70°F. For comparison purposes, 2219 alloy aged in the plant to -T87 temper (S-298772) was coated similarly. All samples were then exposed to the 5% NaCl continuous spray for 168 hours. The corrosion results are shown in Table 20.

Excellent results were obtained on the metal that had received only 8 hours of aging,while the usual degree of corrosion was encountered on the plant produced -T87 and on the 64 hour laboratory aged samples. The intermediate aging times resulted in a corrosion resistance in between these two levels.

The excellent performance of the 8 hour aged material (770 mv) was not too surprising, since it has been demonstrated that -T37 temper (645 mv) yields good corrosion resistance when chromate coated. These data suggest, then, that artificial aging time, or degree of precipitation, will affect the protective value of subsequently applied chromate coatings. However, the problem is far more complex than this, for the degree of aging also affects mechanical properties and resistance to stress corrosion, each of which is dependent on a minimum level of aging.

Effect of 10 oz/gal. Iridite on Other Alloys

In view of the improved results of a 10 oz/gal. Iridite treatment on 2219 alloy, it was important to know what effect it would have on other aluminum alloys that might be employed in the space program. Accordingly, samples of 2014-T6, 5052-H38, 6061-T6, and 7075-T6 material, described in Table 4, were inhibited alkaline cleaned, etched in hot sulfuric acid-chromic acid, and de-smutted in nitric acid. Iridite coatings were then applied from a 10 oz/gal. solution at 70°F, using a one minute immersion for 2014 and 7075 alloys and 30 seconds immersion for 5052 and 6061 alloys. All samples were then exposed to the 5% NaCl continuous spray at 95°F for 168 hours.

Table 21 summarizes the coating weights and the corrosion data for these samples. Good results were obtained, and it would be concluded that a 10 oz/gal. Iridite concentration could be employed on alloys other than 2219 without detrimental effects.

DOUBLE COATING

When a coated metal surface shows weak areas, it is sometimes possible to effect an improvement by employing a secondary coating operation. This approach was considered on 2219-T87 alloy in three ways:

1. Employing the same Iridite solution for both coating operations.
2. Employing an Iridite treatment for one coating and an amorphous chromium phosphate process (for aluminum) for the second.
3. Employing an Iridite treatment in conjunction with a conversion coating process suitable for copper.

In the first item, 1.25 and 10 oz/gal. Iridite treatments were used, separately and in conjunction with each other. An aging delay of 18 hours was employed after the first coating application to obtain an insolubilizing effect on the film prior to the second treatment. These samples were then evaluated in the 5% salt spray, and no advantage was observed over the single coated controls.

For Item 2, an Alodine 401-45 treatment was employed to form the amorphous chromium phosphate film. This was used in combination with 1.25 and 10 oz/gal. Iridite solutions, and comparisons were made with control samples of the three treatments used singly. It was known from previous work that an amorphous chromium phosphate coating is not suitable for protecting 2219 alloy in the salt spray, and this was verified again on the control sample. Similarly, depending on the order of application, the combination of Iridite and amorphous chromium phosphate coatings were either poorer or no better than the Iridite controls.

Item 3 was prepared in the same manner as Items 1 and 2, except that the second coating treatment consisted of solutions of dichromate plus sulfate, chloride, or bromide, which are reported to be applicable to copper alloys. The objective was to provide a filming action on copper constituents which perhaps remain uncoated through an Iridite treatment. However, no advantage was observed for any of the combinations tried, and frequently a detrimental effect was encountered.

One other approach was considered. This involved the use of an acid purging treatment after an initial Iridite coating and then following with a secondary coating operation. Both 1.25 and 10 oz/gal. Iridite solutions were tried, and nitric acid was used in the purging step. Since the objective was to selectively remove deleterious surface contaminants, the first Iridite coating was aged to develop a general insolubility of the coating itself before immersion in the nitric acid solution. The various samples prepared and the salt spray results obtained are shown in Table 22. It is apparent that none of the modifications tried produced any improvement over the standard 1.25 and 10 oz/gal. controls.

In summary, double coating operations have not been successful in improving the salt spray performance of chemically coated 2219-T87 alloy. The particular combinations tried were at best only equivalent to a single coated Iridite control, and in many cases the results were actually poorer.

SEALING TREATMENTS

Another possible approach to the improvement of the corrosion resistance of conversion coated 2219-T87 alloy was the use of a sealing treatment following the coating treatment. Solutions containing hexavalent chromium seemed the most likely for this purpose. Consequently, sodium dichromate at pH 6, sodium chromate at pH 9, and chromic acid at pH 2.2 were evaluated, the latter both with and without a final water rinse. In addition, a strontium nitrate treatment was also investigated, in the hope that relatively insoluble and hence slowly leachable strontium chromate might be formed in the film. This could extend the release of inhibitor over a much greater period of time.

An evaluation of these treatments in the 5% NaCl continuous spray indicated that while some improvement was obtained with sealing, none of these sealing techniques was outstanding for providing corrosion resistant coatings on 2219-T87 alloys. The best overall results were obtained by sealing in 5% $Na_2Cr_2O_7 \cdot 2H_2O$, pH 6.0, 140°F, 3 minutes.

Dichromate Sealing Variations

To further explore the potentialities of dichromate sealing, a test was conducted to evaluate 10% and 50% $Na_2Cr_2O_7 \cdot 2H_2O$, at room temperature and 180°F, with sealing following coating immediately and after 18 hours. Panels of 2219-T87 alloy (S-298772) were inhibited alkaline cleaned, etched in hot H_2SO_4-CrO_3, de-smutted in HNO_3, and coated in 1.25 oz/gal. and in 10 oz/gal. Iridite solutions. Sealing was then conducted under the above conditions and the samples exposed to the 5% NaCl continuous spray for 168 hours. Table 23 summarizes the test samples and the corrosion data Best results were obtained with 10% $Na_2Cr_2O_7 \cdot 2H_2O$ at 180°F, with the sealing immediately following the coating operation. However, these results were not greatly different from the 5% dichromate seal described above, and this approach does not appear to offer a means for obtaining the necessary resistance.

Cathodic Sealing

Since cathodic chromate treatments have been mentioned in the literature for improving corrosion resistance on other metals and coatings, it was considered of value to determine if such a treatment might improve the performance of Iridite coated 2219-T87 alloy. Consequently, coated panels were cathodically "sealed" at 25, 50, and 100 asf for 40, 20, and 10 seconds in a 5% chromic acid solution at room temperature. Subsequent salt spray exposure showed no real advantage for the cathodic treatment.

Silicate-Chromate Sealing

Inasmuch as dichromate solutions alone had not produced the desired results and appeared to need another component, it seemed of value to determine the protective properties that could be obtained by silicate-chromate sealing combinations. Although a number of silicates were investigated, the only one that showed to advantage was the Philadelphia Quartz Co. Kasil #1. Kasil #1 is a liquid potassium silicate material and was employed at a concentration of 2.5% and a temperature of 180°F. Best results in the salt spray test were obtained when 2.5% sodium chromate was added to the Kasil solution.

The better performance of Kasil over similar sodium silicates suggests that perhaps potassium salts may be more effective than sodium salts in this application. Therefore, another salt spray test was devised to compare Kasil sealing followed by potassium dichromate sealing, Kasil plus potassium chromate sealing, dichromate sealing alone and hot distilled water sealing. Panels of 2219-T87 alloy were alkaline cleaned at 180°F, etched in H_2SO_4-CrO_3 at 180°F, de-smutted in HNO_3 and coated for 3 minutes at 85°F in 1.25 oz/gal. Iridite at pH 1.5 and pH 0.9. All samples were aged for 18 hours after coating and before sealing. The panels were then exposed to the 5% NaCl continuous spray at 95°F for 168 hours. Table 24 summarizes the samples and the corrosion results.

In all cases the water sealing had a definitely detrimental effect, and the hexavalent chromium sealing alone showed no advantage over the unsealed controls. The Kasil-potassium chromate treatments did aid the corrosion resistance of the Iridite coating, and it did not seem to matter whether this sealing was done in two steps or in a single combination step. These results suggest that a combination of a heavy Iridite coating and a Kasil-chromate seal might produce the desired results. Before any sealing treatment could be recommended for use, it would also have to be evaluated for its effect on paint adhesion.

The above work was then continued on similarly cleaned panels of 2219-T87 alloy (S-298781), by coating in (a) 1.25 oz/gal. Iridite at pH 1.5, (b) 1.25 oz/gal. Iridite at pH 0.9, and (c) 10 oz/gal. Iridite, and then sealing in Kasil-potassium chromate. The results of a 168 hour salt spray exposure are shown in Table 25. On this lot of metal, excellent results were obtained with the combination of a 10 oz/gal. coating solution and the Kasil-chromate sealing solution.

The next factor considered with respect to employing an alkaline silicate-chromate solution as a sealing treatment for an amorphous chromate conversion coating was the effect on organic coating adhesion. Since NASA coating systems on 2219 alloy involve a zinc chromate primer, a test was conducted to determine the effect of the sealing treatment on primer adhesion. Various conversion coatings were applied and then followed with 0.0005" of TT-P-645 zinc chromate primer. Adhesion as coated and after exposure to 0.5% NaCl solution was evaluated, and the results are shown in Table 26. Although Kasil-K_2CrO_4 sealing does not affect zinc chromate adhesion in a dry adhesion test, it does lead to failure in the more selective immersion test. All the unsealed coating combinations were satisfactory, however.

In summary, it appears that a Kasil-K_2CrO_4 sealing treatment, in conjunction with a 10 oz/gal. Iridite coating treatment, can produce an improved salt spray performance on at least some lots of 2219-T87 alloy. However, regardless of any improvement in corrosion resistance, silicate-chromate sealing has a detrimental effect on zinc chromate primer adhesion. Therefore, if could not be specified on assemblies involving painted areas.

Zinc Additions to Sealing Solutions

In an effort to eliminate the paint adhesion problem of silicate-chromate sealing solutions, the addition of zinc ions to a hexavalent chromium solution was investigated. Combinations of 2% CrO_3 and 0.5 and 1.0% ZnO were tried at room and elevated temperatures on both 1.25 and 10 oz/gal. coatings. The preparation of these samples and the salt spray results obtained are shown in Table 27. As suggested by the table, best results were produced on a 10 oz/gal. coating by sealing in 2% CrO_3, 1% ZnO (pH 5.6) for 3 minutes at 150°F, although the improvement over the 10 oz/gal. control was rather slight.

The work on the CrO_3-ZnO type sealing solution was continued by increasing the concentration of both components. Sealing was conducted at 75°F and 150°F, immediately and after aging the coating. Samples of 2219-T87 alloy, S-298772, 3" x 6" x 0.125", were inhibited alkaline cleaned, deoxidized in hot sulfuric acid-chromic acid, de-smutted in nitric acid and coated for 3 minutes in 1.25 oz/gal. Iridite at 85°F or in 10 oz/gal. Iridite at 70°F. Half of the samples were sealed immediately after coating; the remaining samples were coated and aged for 18 hours and then sealed. The first group of samples were exposed in one salt spray test and the remainder in a second. Tables 28 and 29 summarize the treatments employed and the corrosion results obtained.

Immediate sealing, regardless of conditions, did not effect an improvement on a 1.25 oz/gal. Iridite coating, although in most cases it was not harmful either. With immediate sealing on the 10 oz/gal. coating, equal or slightly better results were obtained when the sealing treatments were employed at 150°F. At the 75°F sealing temperature, results were all slightly poorer than the unsealed control.

Delayed sealing also did not improve the salt spray resistance of 1.25 oz/gal. coatings, and the sealed and unsealed samples were very similar in appearance. On the 10 oz/gal. coatings, delayed sealing at 75°F produced a definite improvement at all three sealing solution concentrations. However, 150°F sealed samples were comparable to the unsealed control. This represents a response just the opposite of that encountered with immediate sealing.

Although there is no question that certain of the samples in the above test showed an improved performance, the question must be raised as to whether this improvement actually resulted from a sealing action. First of all, sealing should have shown at least a slight effect on the 1.25 oz/gal. coatings, and none was observed. Secondly, on the 10 oz/gal. coatings, there was the unexplained variable response between 75°F and 150°F solution temperatures when sealing was conducted immediately or after 18 hours. Therefore, an advantage for sealing in a solution of zinc ions and hexavalent chromium has not been conclusively demonstrated.

As indicated previously, a suitable sealing treatment, in the course of improving the salt spray resistance of the Iridite coating, must not have a harmful effect on zinc chromate primer adhesion. Although a CrO_3-ZnO sealing treatment would not be expected to have an adverse effect on this type of primer, it was necessary to obtain a verification.

Therefore, panels of 2219-T87 alloy, S-298772, 3" x 6" x 0.125", were cleaned in the usual way, coated in a 10 oz/gal. Iridite solution, and sealed in a 10% CrO_3-5% ZnO solution at 75°F and at 150°F, both immediately and after 18 hours. Two samples of each condition were coated with 0.0005" TT-P-645 zinc chromate primer and air dried for 24 hours.

The zinc chromated samples were tested for adhesion, as coated by scoring with a Gitterschnitt tool and pulling with Scotch Tape, and after immersion for 72 hours in 0.5% NaCl solution at room temperature by pulling with Scotch Tape without scribing. Table 30 summarizes these samples and the test results. All surfaces were rated satisfactory for bonding zinc chromate primer, even though some slight pick-off was observed on the 72 hour immersion samples.

OPERATION PROBLEMS OF IRIDITE SOLUTIONS

Laboratory Evaluation of Solution Life

Possible changes in the coating solution as it is used must always be considered, and this is especially important when the material to be coated is as highly alloyed as 2219. Therefore, a test was designed to compare the following Iridite solutions:

1.25 oz/gal.
1.25 oz/gal. adjusted with HNO_3
6 oz/gal.
10 oz/gal.

For each solution the CrO_3 content, pH, and resulting conversion coating weight were determined initially, after processing 3 to 3.5 square feet of metal surface per liter, and after final adjustment. Corrosion test samples were also prepared at each of these three stages. Table 31 summarizes the data on the condition of the solution, and Table 32 shows the corrosion results.

As anticipated, the use of an Iridite solution causes a decrease in the hexavalent chromium content, an increase in pH, and a decrease in the conversion coating weight produced. Usually, the addition made to adjust the solution restored the coating weight to the initial value. In the salt spray test, there were no appreciable differences among the various samples for the two 1.25 oz/gal. solutions or the 6 oz/gal. solution. The 10 oz/gal. treatment, however, merits some further discussion.

On the 10 oz/gal. coating, better results were obtained initially than after use or adjustment. This would at first suggest that the bath had become contaminated, beyond simple depletion of the components. However, it was also observed that the "used" and "adjusted" samples were badly leached after the salt spray exposure, while the "initial" sample retained considerable color. Because of the nature of this particular test, some delay was unavoidable between the preparation of the initial and final samples. Thus, the "used" and "adjusted" samples were exposed rather promptly after preparation, while the "initial" sample had aged for about a week. While the contamination of a 10 oz/gal. Iridite solution with aluminum or copper could certainly have an adverse effect on the coating, it is also likely that other factors, such as the storage interval before exposure, may have an equally important effect.

Pilot Plant Scale Test

A pilot plant scale test was scheduled for the 10 oz/gal. Iridite 14-2 bath in order to assess some of the production problems and to determine the effect of extended use on bath performance. This was conducted at the Alcoa Process Development Laboratories, Merwin, Pennsylvania, and involved a solution volume of 250 gallons.

Since production Iridite baths for space vehicle parts involve thousands of gallons and since they are now prepared with tap water, it was anticipated that tap water could be used for the new 10 oz/gal. solution as well. However, it was quickly found that a 10 oz/gal. solution made with tap water yielded powdery coatings. This powdering could not be eliminated by aging the bath, lowering the operating temperature to 50°F, or reducing the immersion time.

A standard 1.25 oz/gal. bath, pH 1.5, could be prepared with tap water to produce tight coatings. This same bath with the pH reduced to 0.9 with nitric acid and also the previously studied 6 oz/gal. bath produced powdery coatings similar to the 10 oz/gal. solution. All concentrations formed satisfactory films when either distilled or de-ionized water was used.

An analysis was obtained on this water, which comes initially from the Allegheny River and is treated and distributed by the New Kensington Water Department. The results of the analysis are shown in Table 33. Actually, this water is of relatively good quality, showing only 22 ppm of chloride and 128 ppm of sulfate.

Sulfate is known to poison chromate conversion coating solutions and was the first suspect in this problem. To evaluate it, a 10 oz/gal. solution was prepared with distilled water, and increasing amounts of sulfate were added in an attempt to produce powdering. A concentration of 1000 ppm was reached and the coating was still tight.

Similarly 25 ppm of chloride was added to a distilled water solution containing 10 oz/gal. Iridite. The coating did not become powdery. Increasing the chloride content to 50 ppm affected the coating only slightly. When 150 ppm sulfate was added to this last solution, the beginning of powdering was observed.

The synthetic solutions that showed the degree of powdering observed with tap water involved adding 150 ppm sulfate to the de-ionized water before dissolving the Iridite and then adding 25 ppm of chloride afterwards; or adding both the sulfate and chloride to the de-ionized water before dissolving the Iridite; or adding 25 ppm chloride only to the water before dissolving the Iridite. Time did not permit further work on the effect of impurities.

Whatever the contamination mechanism involved, apparently the more active Iridite solutions are also the more sensitive. An effort was made to recover a 10 oz/gal. in tap water solution with various additives. None was successful, and at this time we do not know of any satisfactory method for reviving a 10 oz/gal. bath in this condition. Accordingly,it is necessary to specify that distilled or de-ionized water be employed for Iridite 14-2 solutions more active than 1.25 oz/gal. at pH 1.5.

The pilot plant test was then conducted, using de-ionized water to prepare the 250 gallons of Iridite 14-2 at a concentration of 10 oz/gal. Repetitive loads of 2219-T87 alloy sheet were coated in this solution for 3 minutes at 70°F, stripping the coating in 50% HNO_3 after each treatment. Air agitation was employed between loads but not during the coating operation. Initially and after every 1 ft^2/gal. processed, exposure samples were prepared and a sample of the solution was retained for analysis. Thus, the bath was aged as it would be in production use, and in the time available to us we were able to reach a processing level of 10 ft^2/gal.

Table 34 shows the hexavalent chromium content, the aluminum content, and the coating weight at each ft^2/gal. interval. The pH remained at 0.7 throughout the test. After 10 ft^2/gal. had been processed, the hexavalent chromium content had changed from 23.0 g/l to 22.4 g/l (44.3 g/l to 43.1 g/l CrO_3), and the aluminum content had increased to 0.051 g/l (48.5 g per 250 gal.). No copper accumulation was detected. The coating weight varied from an initial value of 174 mg/ft^2 to 141 mg/ft^2 after 10 ft^2/gal. Some variability was observed in the hexavalent chromium and coating weight determinations, but the aluminum content increased at a uniform rate. Coatings formed in this pilot plant test were substantially heavier than the laboratory prepared 10 oz/gal. coatings. The reason for this is not apparent, and the greater film weight must therefore be attributed to some as yet undefined characteristic of the equipment and cycle employed.

Exposure samples consisted of 0.125" (S-298772) and 0.50" (S-298778) 2219-T87 alloy which were inhibited alkaline cleaned, etched in hot sulfuric acid-chromic acid, de-smutted in nitric acid and coated for 3 minutes at 70°F. One of each of these samples, together with 1.25 oz/gal. coated control panels, were exposed to the 5% NaCl continuous spray for 168 hours. Table 35 summarizes the samples and the corrosion results. Figures 16 and 17 are photographs illustrating the results.

These results verify that the 10 oz/gal. coating is better than the 1.25 oz/gal. coating. No appreciable difference in performance is evident with use, up to a 10 ft^2/gal. level. However, the 0.50" thick material seems to be slightly better than the 0.125".

Although a longer test, together with bath maintenance additions, would be required to obtain a complete picture of the effect of usage, the above evaluation might serve to indicate other possible production problems. Only two were detected. One is the quality of the make-up water as described above. The second involves fumes from this concentrated coating solution. With normal across-surface tank venting, the fumes are not objectionable. It is believed, however, that venting in some form will be necessary. Finally, it would be of value to consult with the supplier concerning the installation of large volumes of concentrated coating solution, for the purpose of anticipating any other production problems.

EXPOSURE TESTS

Outline of Program

At the conclusion of the first year of the contract an exposure test was prepared to further evaluate the results from the experimental work. This test included 2219 alloy in various tempers, as well as other selected alloy types, and continued on, as required, through the second contract year. Five exposure environments were selected, as follows:

1. 5% NaCl Continuous Spray at 95°F.
2. 100% Relative Humidity at 125°F.
3. New Kensington, Pa. Atmosphere (Industrial).
4. Point Judith, R.I. Atmosphere (Coastal).
5. Miami, Florida Atmosphere (Coastal).

Initial salt spray exposures were for 168 hours, followed by re-exposure to a total of 336 hours. The other exposures were continued for a total period of one year, with some intermittent examinations.

The aluminum samples tested included 2219 alloy in the -F, -T62, -T37, and -T87 tempers, and 2014-T6 (Al-Cu), 5052-H38 (Al-Mg), 6061-T6 (Al-Mg_2Si), and 7075-T6 (Al-Cu-Mg-Zn) alloys. Both chemical and mechanical surface preparations were included, and the coating treatments were as follows:

1.25 oz/gal. Iridite 14-2, pH 1.5, 85°F.
1.25 oz/gal. Iridite 14-2, pH 0.9, 85°F.
6 oz/gal. Iridite 14-2, pH 0.7, 70°F.

An immersion time of 3 minutes was employed with all three coating treatments on 2219 alloy. With the other alloys it was necessary to reduce the time to one minute in the 1.25 oz/gal. at pH 0.9 and in the 6 oz/gal. baths.

Alloys Other Than 2219 - Preparation and Salt Spray Results

The specific lots of 2014-T6, 5052-H38, 6061-T6, and 7075-T6 employed are shown in Table 4 with the chemical analyses.

Mill finish samples, 3" x 6" x 0.064", were cleaned for 3 minutes in 3% inhibited (with silicate) alkaline cleaner at 180°F, etched for 3 minutes in 100 ml/l 96% H_2SO_4, 35 g/l CrO_3 at 180°F, and immersed for 30 seconds in 50% HNO_3 at 80°F. Conversion coatings were applied from the following solutions: 1.25 oz/gal. Iridite 14-2, pH 1.5, 85°F, 3 minutes; 1.25 oz/gal. Iridite 14-2, pH 0.9, 85°F, 1 minute; 6 oz/gal. Iridite 14-2, pH 0.7, 70°F, 1 minute.

In addition, similar samples were prepared by Scotch-Brite brushing the surfaces with a Flap Brush #50S, Fine, 8" diameter, 1750 rpm. These samples were then cleaned for 3 minutes in 3% inhibited alkaline cleaner at 180°F and coated in 1.25 oz/gal. Iridite 14-2, pH 1.5, at 85°F for 3 minutes.

Coating weights for the various alloys and coating procedures are shown in Table 36. All of the coatings were tight except for the 6 oz/gal. Iridite on 7075-T6 alloy. This coating was chalky and tended to wash off in the rinse water. It was noteworthy that the Scotch-Brite treatment, as employed here, increased the coating weight obtained on 2014 and 7075 alloys but actually had an inhibiting effect on 5052 and 6061 alloys.

Replicate samples were prepared for salt spray and humidity accelerated tests and for New Kensington, Pa., Pt. Judith, R.I., and Miami, Florida atmospheric exposures. Three samples of each item have been designated for each of these environments. Table 37 indicates the various samples and exposure tests.

The 5% salt spray test, for the initial period of 168 hours, was conducted first. Since the ARL salt spray cabinet employed on this program can accomodate up to 24 samples at a time, multiple exposures were necessary.

Samples of 5052 and 7075 alloys were evaluated in the first test, and samples of 2014 and 6061 alloys were evaluated in the second. Tables 38 and 39 show the results on these alloys after the first 168 hours. Excellent protection was obtained on 5052 alloy with all of the coatings, but on 7075 alloy only the 1.25 oz/gal. bath at pH 0.9 produced a completely corrosion-free surface after 168 hours' exposure. Similarly, in test No. 2, excellent results were obtained on 6061 alloy with all treatments; and satisfactory results were obtained on 2014 alloy with all except the standard 1.25 oz/gal. solution at pH 1.5. Figures 18 to 25 are photographs showing the appearance of these samples after the 168 hours' salt spray exposure.

These samples were then re-exposed to the salt spray for another 168 hours, making a total exposure of 336 hours. Tables 40 and 41 summarize the results. All of the 5052 alloy samples were still in excellent condition and showed no corrosion. The 7075 alloy samples now showed increased attack, with the best results still obtained with 1.25 oz/gal. Iridite adjusted to pH 0.9. Results similar to 7075 alloy were observed with 2014-T6, but all of the 6061-T6 alloy samples were in excellent condition. Figures 26-33 are photographs showing the appearance of these samples after the 336 hours exposure.

As expected, Iridite coated 5052 and 6061 alloys will readily meet either the original MIL-C-5541 specification (168 hours salt spray exposure) or the revised version (336 hours salt spray exposure). Although 2014 and 7075 alloys can be made to pass the 168 hour exposure satisfactorily, there is some question concerning the extended exposure. It should be noted, however, that the salt spray test described above might be abnormally severe because the samples were removed after the first 168 hours for photographing. Accordingly, the samples were subjected to rinsing, drying and a delay period prior to completion of the exposure. On copper and zinc bearing alloys, such as 2014 and 7075, an ultimate evaluation with respect to the revised MIL-C-5541 should be based on a continuous, rather than an interrupted exposure of 336 hours to the 5% NaCl spray.

Description of 2219 Alloy Samples

Several aspects were important in the evaluation of 2219 alloy, such as the comparison of other tempers with -T87, the effect of gage, and the reproducibility of results from one lot of metal to another. The various lots of metal employed for the exposure program are included in Table 1, showing chemical analyses. Table 2 shows hardness and solution potential values for these same lots. The -F (as fabricated), -T37, and -T87 temper samples were all received as such from plant production, while -T62 was produced at Alcoa Research Laboratories by heat treating and aging -F material. Replicate samples were prepared for the various exposures, with 2 samples allotted to each of the accelerated tests and 2-3 to each of the atmospheric tests.

-F Temper, 0.50", S-290082 - Preparation and Salt Spray Results

Mill finish 3" x 6" x 0.50" samples of 2219-F alloy were prepared by cleaning for 3 minutes in 3% inhibited alkaline cleaner at 180°F, etching for 3 minutes in 100 ml/l 96% H_2SO_4, 35 g/l CrO_3 at 180°F, and de-smutting for 30 seconds in 50% HNO_3 at 80°F. Conversion coatings were applied by the following three treatments:

1. 1.25 oz/gal. Iridite 14-2, pH 1.5, 85°F, 3 minutes.
2. 1.25 oz/gal. Iridite 14-2, pH 0.9, with HNO_3, 85°F, 3 minutes.
3. 6 oz/gal. Iridite 14-2, pH 0.7, 70°F, 3 minutes.

The coating weights obtained and the exposure distribution are shown in Table 42. The salt spray samples for this temper were included in Test No. 3, and the results for the first 168 hours are included in Table 43. It is apparent that the -F temper material was at least as susceptible to salt spray corrosion as -T87 temper material. Best results were obtained by adjusting the bath pH to 0.9 with HNO_3 or by increasing the concentration to 6 oz/gal. Figure 34 is a photograph of the samples after the 168 hours exposure. It is interesting to note that this relatively poor corrosion resistance on the -F temper was obtained even though the coating weights were higher than on the -T87 temper.

After re-exposure to a total of 336 hours, all of the 2219-F alloy samples showed severe corrosion. Of the three treatments employed, the 1.25 oz/gal. Iridite at pH 0.9 performed very slightly better than the other two. The results are summarized in Table 44, and Figure 35 is a photograph of the panels.

-T62 Temper, 0.50", S-298551 - Preparation and Salt Spray Results

Mill finish 3" x 6" x 0.50" samples of 2219-T62 alloy were prepared by alkaline cleaning and acid etching as described above, and the same three conversion coating treatments were employed. The coating weights and the exposure distribution are shown in Table 45. The salt spray samples for this temper were exposed in Test No. 5, and the results for the first 168 hours are shown in Table 46. Only very mild corrosion was obtained with the standard 1.25 oz/gal. and the 1.25 oz/gal. at pH 0.9 treatments, while no corrosion was observed with the 6 oz/gal. treatment. Figure 36 is a photograph of these samples after the 168 hours exposure.

On re-exposure to a total of 336 hours, the 2219-T62 alloy samples showed severe to moderate corrosion. Poorest results were obtained with 1.25 oz/gal. Iridite at pH 1.5 and the best with 6 oz/gal. Iridite at pH 0.7. These results are summarized in Table 47 and Figure 37.

-T37 Temper, 0.50", S-290081 - Preparation and Salt Spray Results

Mill finish 3" x 6" x 0.50" samples of 2219-T37 alloy were prepared by alkaline cleaning and acid etching as described above, and the same three conversion coating treatments were employed. The coating weights and the exposure distribution are shown in Table 48. The salt spray samples for this temper were included in Test No. 3, and the results for the first 168 hours are shown in Table 43. Mild corrosion was obtained with the standard 1.25 oz/gal. treatment, but there was no corrosion at all when the pH was adjusted to 0.9 with HNO_3 or the concentration increased to 6 oz/gal. Figure 38 is a photograph of these samples after the 168 hours exposure.

After re-exposure to a total of 336 hours, the panels coated in the 6 oz/gal. Iridite solution showed only mild corrosion. The samples with the other two treatments were severely attacked, however. The test data are summarized in Table 44, and Figure 39 is a photograph of the exposure samples.

-T87 Temper, 0.50", S-290080 - Variability Through Plate - Preparation and Salt Spray Results

Samples of 2219-T87 alloy, 3" x 6" x 0.50" were sawed longitudinally to expose a surface in the interior region of the plate. The resulting panels were 3" x 6" x approximately 0.25", with one face a sawed surface from the interior of the plate and the other the outer mill finish surface. A comparison was then made between these two surfaces, using machining and inhibited alkaline cleaning as the preparation. The coating treatment was limited to 1.25 oz/gal. Iridite, pH 1.5, 85°F, 3 minutes. The coating weights and the exposure distribution are shown in Table 49. The salt spray samples for this comparison were included in Test No. 3, and the results for the first 168 hours are shown in Table 43. Good corrosion resistance was obtained with the standard treatment on both of these machined surfaces, and the interior region of the plate responded the same as the exterior. Figure 40 is a photograph of the samples after the 168 hours exposure.

The good initial performance of these panels was not retained when the exposure was continued from 168 to 336 hours. However, the interior region still responded the same as the exterior. The results are shown in Table 44, and Figure 41 is a photograph of the samples.

-T87 Temper, 0.50", S-298548 - Effect of Chemical Milling - Preparation and Salt Spray Results

Mill finish 3" x 6" x 0.50" samples of 2219-T87 alloy were prepared by alkaline cleaning and acid etching as described above and the three coating treatments applied.

Additional 3" x 6" samples were chemically milled to remove about 0.060" from one surface, cleaned in the 3% inhibited alkaline solution at 180°F for 3 minutes, and coated with the above three Iridite treatments.

A third group of samples were machined on one surface, cleaned in the inhibited alkaline solution, and coated with the standard 1.25 oz/gal., pH 1.5, Iridite treatment only.

The coating weights and the exposure distribution for all of these samples are shown in Table 50. The salt spray samples were exposed in Test No. 4, and the results for the first 168 hours are shown in Table 51. Neither the acid etched mill finish samples nor the chemically milled samples showed adequate corrosion resistance with any of the three Iridite treatments. On both, the results were slightly better with the pH adjusted to 0.9 with HNO_3 or the concentration increased to 6 oz/gal. When the surface was machined, however, the standard 1.25 oz/gal. treatment provided complete protection. Figures 42, 43, and 44 are photographs of these various samples after the 168 hours exposure.

After the exposure had been extended to 336 hours, all the chemically milled samples showed considerable corrosion, with the 1.25 oz/gal. Iridite at pH 0.9 treatment performing slightly better than the other two. This same treatment was also the best on the mill finish samples, these panels showing only moderate corrosion. The machined panels, with the 1.25 oz/gal. Iridite at pH 1.5 treatment, also showed moderate corrosion. The results are summarized in Table 52, and Figures 45, 46, and 47 are photographs comparing the various samples.

-T87 Temper, 0.125", S-298529 - Effect of Sealing - Preparation and Salt Spray Results

Mill finish 3" x 6" x 0.125" samples of 2219-T87 alloy were prepared by alkaline cleaning and acid etching as described previously and then coated in a 1.25 oz/gal. Iridite solution with the pH adjusted to 0.9 with HNO_3. The samples were divided into two groups, and one group was given an additional sealing treatment in 5% $Na_2Cr_2O_7 \cdot 2H_2O$, pH 6.0, 140°F for 3 minutes. The coating weight and the exposure distribution are shown in Table 53. The salt spray samples for this comparison were included in Test No. 3, and the results for the first 168 hours are shown in Table 43. None of the samples showed adequate corrosion resistance, and the dichromate sealing treatment did not contribute any significant improvement. Figure 48 is a photograph of the samples after the 168 hours exposure.

Extension of this test to 336 hours did show a slight advantage for the sealing treatment, however. The sealed samples were moderately corroded and approximately comparable to those described above. A summary of the results is included in Table 44, and Figure 49 is a photograph of the panels.

-T87 Temper, 0.125", S-298552 - Comparison of Acid Etching Treatments - Preparation and Salt Spray Results

Mill finish 3" x 6" x 0.125" samples of 2219-T87 alloy were prepared by cleaning for 3 minutes in a 3% inhibited alkaline cleaner at 180°F and then acid etching for 3 minutes in one of the following solutions:

1. 100 ml/l 96% H_2SO_4, 35 g/l CrO_3 at 180°F.
2. 100 ml/l 70% HNO_3, 10 ml/l 48% HF at R.T.
3. 100 ml/l 96% H_2SO_4, 50 ml/l 70% HNO_3 at 150°F.

A nitric acid de-smutting treatment was applied in each case. Samples with these three different surface preparations were then given the three Iridite coating treatments described above.

Another group of samples was prepared with the 3M Scotch-Brite treatment and cleaned in the inhibited alkaline cleaner. These also were subjected to the three Iridite coating treatments.

The coating weights and exposure distribution for all the samples are shown in Table 54. The salt spray samples were exposed in Test No. 6, and the results for the first 168 hours are shown in Table 55. None of the acid etch and Iridite coating combinations produced adequate corrosion resistance. The H_2SO_4-HNO_3 acid etching treatment seemed to be slightly better than the others, and the adjusted pH and 6 oz/gal. Iridite baths produced a slightly more protective coating. Markedly better results were obtained when Scotch-Brite was employed as the pretreatment, and the 6 oz/gal. Iridite coating was the best, showing only very mild corrosion. Figures 50, 51, 52, and 53 are photographs of these samples after the 168 hours exposure.

When the exposure was extended to 336 hours, all of the acid etched samples showed severe corrosion with all three coating treatments. The Scotch-Brite pretreatment showed severe corrosion only with the 1.25 oz/gal. Iridite at pH 1.5; the 1.25 oz/gal. Iridite at pH 0.9 and the 6 oz/gal. samples were only moderately corroded. These data are summarized in Table 56, and the panels are illustrated in Figures 54, 55, 56, and 57.

Humidity Exposure Results

Exposure to 100% relative humidity at 125°F is a rather mild test for Iridite coated aluminum alloys, and the first evaluation was recorded after a 3 months interval. These results are shown in Tables 57, 58, 59, and 60. Although some staining had occurred, none of the samples showed any attack with formation of corrosion product.

The exposure was then continued to a total period of one year. Tables 61, 62, 63, and 64 show these results. On the other alloys 5052 and 6061 showed no pitting, while 2014 and 7075 had a mild, scattered pitting attack. There was not a great difference as a result of temper on 2219 alloy, although -T62 seemed to be the best of those tested. The various chemical pretreatments performed similarly and were not quite as effective as machining or Scotch Briting. Similarly, the three coating treatments produced about the same results. In general, the attack on the various samples in 100% relative humidity at 125°F would be considered rather mild. Figures 58-62 are photographs of representative samples from this exposure.

New Kensington Atmosphere Exposure Results

All three of the atmospheric exposure tests had been scheduled for return and examination after one year. Because of its proximity, the New Kensington, Pa. test was followed closely throughout the one year interval. The attack on Iridite coated aluminum alloys in this environment was relatively mild and progressed slowly. At the conclusion of the one year exposure, the panels were removed for examination and evaluation. Results are shown in Tables 65, 66, 67, and 68.

On the other alloys, 5052 and 6061 showed no corrosion, while 2014 and 7075 had only a very mild attack. With respect to temper on 2219 alloy, the -T37 samples showed no corrosion and were the best tested. Machining, Scotch-Briting, and chemical milling all were slightly more effective surface preparations than the usual chemical deoxidizers. The three coating treatments appeared to produce equivalent results, and the overall attack in this environment would not be considered severe. Figures 63-67 are photographs of representative samples from this exposure.

Point Judith, Rhode Island Exposure Results

Point Judith, R.I. is a northern sea coast exposure and was the most severe atmospheric environment employed in this program. A check examination of the samples was conducted on the site after 4 months, and they were removed for evaluation after one year. The results of the one year exposure are shown in Tables 69, 70, 71, and 72.

Best results on alloys other than 2219 were obtained on the 5052 alloy samples, which showed a very mild uniform pitting. On 2219 alloy, the -T37 temper seemed somewhat better than the others tested. Surface preparation of the -T87 temper by machining or Scotch-Briting resulted in a slightly more protective coating than the chemical treatments. There was not a great difference in the performance of the three coating systems, although any advantage would go to the pH 0.9 or 6 oz/gal. solutions. Figures 68-72 are photographs of representative samples from this exposure.

Miami, Florida Exposure Results

The Miami exposure represents a southern coastal environment. It is less severe than Point Judith, perhaps because of the relative proximity of the two stations to the sea. On the other hand, a Florida coastal exposure is important in this program in view of the role of Cape Kennedy as a launching center. The Miami samples were returned for examination and evaluation after a total period of one year. Results are shown in Tables 73, 74, 75, and 76.

The alloys other than 2219 performed well in this exposure, showing no corrosion on 5052 and 6061 and only very mild attack on 2014 and 7075. On 2219 alloy, the -T37 temper was best with no corrosion, followed closely by -T87 with only very mild attack. Surface preparation was not especially critical nor was the particular coating solution employed. In general, there was a relatively small amount of corrosion on the panels in this exposure and almost no evidence of white corrosion product. Figures 73-77 are photographs of representative samples from the Miami exposure.

DISCUSSION OF CORROSION TEST RESULTS

Salt Spray

The 5% NaCl continuous spray is the accelerated test currently specified for evaluating coating treatments on 2219 alloy space vehicle parts. A minimum exposure of 168 hours without corrosion was requested, and an exposure period of 336 hours, in accord with MIL-C-5541a, would be preferred. These exposure requirements are readily met with a 15 minute sulfuric acid anodic coating at 12 amp/ft^2, sealed for 15 minutes in hot 5% sodium dichromate.

In view of the greater sensitivity of chemically coated 2219 alloy to salt spray attack, two factors must be considered in the evaluation of the results. One is the recognized normal variability from one salt spray cabinet to another and from one test to another in the same cabinet, despite the best efforts to adhere closely to the ASTM specifications. The second factor is a normal variation from lot to lot of 2219 alloy depending on temper, gage, etc. Therefore, it was desirable in the exposure program to test several lots of metal.

The test described above, conducted at the close of the first year's work, verified the difficulty in processing 2219-T87 alloy. On the basis of an evaluation after the first 168 hours, machining or other mechanical finishing yielded a consistently good conversion coating performance. With chemical processing, the coating performance was substantially poorer and subject to variation. The effectiveness of a mechanical finish can be neutralized by following it with a chemical treatment. Metal in the -T37 temper, however, appeared to respond differently to chemical pretreatments, and good protective conversion coatings were obtained. With the -F temper, the reverse was true, and the salt spray performance of the Iridite coating was comparable to that for -T87 temper.

Results for the -T62 temper were unexpected. Since this material was heat treated and aged, lacking only the cold work of the -T87 temper, it was anticipated that it would perform similarly to -T87 when conversion coated. Unlike -T87, the Iridite coated -T62 samples in the above salt spray exposure showed very little corrosion. Although this test consisted of an evaluation of only one lot of metal, nevertheless the significantly improved performance of 2219-T62 warrants further consideration. Perhaps the precipitation of $CuAl_2$ in the aging operation has less deleterious effect on surface reactivity in the absence of cold work--either in the acid etching or the conversion coating treatment. Whatever the reason, Iridite coated 2219-T62 alloy was acceptible, as evaluated by the 168 hours salt spray test. However, the physical properties of this temper are about the same as 2219-T37, which also was found to have rather good salt spray resistance when Iridite coated.

Although none of the three coatings employed in the exposure test program functioned as desired on 2219 alloy, an improvement was observed going from 1.25 oz/gal. at pH 1.5 to 1.25 oz/gal. at pH 0.9 to 6 oz/gal. By using one of the latter two compositions, it was possible to obtain satisfactory results on the four alloys other than 2219. Therefore, it was generally advantageous to increase the activity of the Iridite solution.

When the exposure was continued to 336 hours, none of the 2219 alloy panels were free from corrosion. Best results were obtained with -T37 temper samples coated in a 6 oz/gal. Iridite bath; these were considered to have mild corrosion. A few other samples had moderate corrosion and are listed in increasing severity of attack, as follows:

2219-T37, S-290081 - 6 oz/gal. Iridite
2219-T87, S-298552 - Scotch Brite and 6 oz/gal. Iridite
2219-T87, S-298552 - Scotch Brite and 1.25 oz/gal., pH 0.9
2219-T87, S-298548 - Machined and 1.25 oz/gal., pH 1.5
2219-T87, S-298529 - 1.25 oz/gal., pH 0.9 and Dichromate Seal.
2219-T87, S-298548 - 1.25 oz/gal., pH 0.9

A previously observed tendency for coated 2219 alloy samples to show abrupt changes during salt spray exposure seemed to be encountered during this second 168 hours. Even the machined samples, which had performed so well during the first exposure, were not able to withstand 336 hours without evidence of attack. An unexpected result with respect to degree of attack was obtained on the dichromate sealed samples. Sealed and unsealed samples were equally corroded during the first 168 hours, but the sealed samples showed less total attack than the unsealed at the end of 336 hours.

Although the interruption of the salt spray after 168 hours may have increased the severity of the test, it is apparent that none of the treatments produced the desired results. However, the previously noted advantages of mechanical pretreatment and pH 0.9 and 6 oz/gal. Iridite baths continued to be substantiated.

It was the advantageous performance of the pH 0.9 and 6 oz/gal. treatments that led to the work with the 10 oz/gal. solution, the corrosion results of which were discussed previously. An important aspect of salt spray resistance is the available hexavalent chromium content and the capacity for releasing it at a controlled rate throughout the exposure period. The 10 oz/gal. coating meets this need more effectively than the other compositions evaluated, although it still does not provide the degree of protection for 2219-T87 alloy that was sought.

Humidity

For exposure periods of at least three months, all of the Iridite coatings produced satisfactory results on all of the alloys and tempers tested. Occasionally some staining was observed, but there was no formation of white corrosion product. Even when the exposure period was extended to a total of one year, the attack was very mild, and there was a minimum of corrosion product. Since it is the corrosion product itself that is of primary concern on space vehicles, it appears that 2219 alloy can be readily protected against a humidity environment. For this reason, storage atmospheres involving only humidity should not present excessive difficulties.

Outdoor Exposures

The most significant aspect of the three outdoor exposures--New Kensington, Point Judith, and Miami--is the importance of chloride in promoting attack on Iridite coated 2219 alloy. A secondary effect is a probable cell action in the New Kensington atmosphere as a result of industrial dirt settling upon the samples.

The one year Point Judith exposure was the most severe, and all alloys and tempers showed at least some attack. In many cases there was a considerable amount of white corrosion product formed. For an exposure of this type, it appears that the salt spray is a very satisfactory accelerated test and offers a good method for screening coating processes.

The Miami exposure was very mild with respect to that of Point Judith, and undoubtedly the amount of chloride reaching the sample surfaces was much less also. New Kensington atmosphere is industrial and, while relatively low in chloride, certainly offers an acid environment in the presence of carbon. As a result, the attack in this exposure was intermediate between Point Judith and Miami, although still not considered severe.

From these results it would seem that if the coated space vehicle parts were stored in an environment relatively free from chloride, and at the same time shielded from industrial dirt fall-out, they could be protected by a minimum Iridite treatment. With an increasing availability of chloride, however, the problem becomes greater, and a more effective conversion coating is required. For an atmosphere as severe as Point Judith, it is unlikely that any chromate coating will give entirely satisfactory results.

DISCUSSION OF VARIABLE METAL RESPONSE

It has been generally recognized that when 2219-T87 alloy is chromate conversion coated and exposed to the 5% NaCl continuous spray the degree of corrosion can vary noticeably from one lot of metal to another. This effect is in addition to what might be expected from a normal operation of the salt spray test or from a normal commercial application of the conversion coating. As a result, the variability appears to be related to subtle differences in the product, which are not, however, reflected in changes in strength or in resistance to stress corrosion.

When 2219 alloy is in the -T37 temper, it does not have the physical properties nor the resistance to stress corrosion cracking desired, but it does form the most protective chromate conversion coating. An inadequate thermal aging toward the -T87 temper will improve the physical properties, while retaining the quality of the conversion coating, but the product would still be susceptible to stress corrosion cracking. The latter will be overcome by fully aging to -T87, and it is at this point that the variable response to chromate coating is observed.

A survey of the various lots of 2219-T87 alloy used in this program indicates that thin gage material (0.125") forms a less protective coating than thicker material (0.50" or more). This could be caused by a differential rate of heating and cooling in the thermal treatment, as well as by different amounts of effective cold work imposed on the material during rolling. In addition to the effect of gage, there is a slight indication that better coating performance can be obtained when the copper content is in the lower half of the allowable range.

Microscopic examinations have not proven to be especially satisfactory for demonstrating the reasons for differential coating performance. Two factors are worthy of mention, however. First, slight differences in the amount of $CuAl_2$ precipitate are sometimes detected. In this regard, thin gage 2219-T87 seems to show more precipitate than heavy gages. Secondly, differences are sometimes observed in the relative ratio of grain boundary to grain body precipitate. This would vary the potential difference between the grain boundary region and the grain body, which could in turn affect the corrosion resistance after chromate coating.

The inability of a metallographic examination to provide more definitive evidence has precluded the opportunity for predicting the performance of a given lot of material, or for avoiding lot to lot variations that would affect chromate coating response. Thus it has been desirable to develop a chemical coating that could overide undefined metal differences and provide the desired salt spray resistance, in a manner equivalent to a sulfuric acid anodic coating.

CONCLUSIONS

1. Chromate conversion coatings of the Iridite 14-2 type provide a substantial protection to 2219 alloy in salt spray exposures through the presence of an anodic inhibitor, hexavalent chromium, in the coating.

2. Thermal treatments decrease the corrosion resistance of Iridite coatings by rendering the hexavalent chromium content less soluble and thus preventing it from being leached in sufficient amount to serve as an effective inhibitor.

3. Extended storage at ambient temperatures also decreases the corrosion resistance of Iridite coated 2219-T87 alloy, probably through the same mechanism as with a thermal treatment.

4. Factors affecting Iridite film weight are surface preparation of the aluminum, and pH, concentration, temperature, and time in the Iridite solution. The relationship of these variables determines whether the coating is adherent or non-adherent.

5. The ferricyanide accelerator in the Iridite solution both increases the rate of coating formation and renders the solution sensitive to pH control.

6. Mechanical surface preparations, such as machining, Scotch-Brite brushing, liquid honing, or glass bead blasting, yield Iridite coatings on 2219-T87 alloy that show excellent salt spray resistance for 168 hours exposure.

7. For optimum conversion coating formation on a machined 2219-T87 alloy surface, it is desirable for the machining operation to be conducted after rather than before thermal aging to the -T87 temper.

8. Chemical surface preparation is less satisfactory than mechanical. It is necessary for the chemical treatment to effectively remove surface oxide without forming a secondary passivating film.

9. When a chemical surface preparation is employed prior to Iridite coating, satisfactory 168 hour salt spray resistance can be obtained with the -T37 temper but not with the -T87 temper.

10. On a given lot of 2219-T87 alloy material, no significant difference was observed at various levels through the thickness of the metal, with respect to the salt spray resistance of the Iridite coating.

11. The salt spray resistance of the Iridite coating is favored by rendering the coating solution more active. This can be done by adjusting the pH of a 1.25 oz/gal. solution to pH 0.9 with nitric acid or by increasing the concentration to 6 oz/gal. or 10 oz/gal. Best salt spray results have been obtained with a 10 oz/gal. solution.

12. Although sealing treatments can supply additional salt spray resistance, a significant improvement was not obtained without the sacrifice of organic coating adhesion properties.

13. The more active Iridite solutions--1.25 oz/gal. at pH 0.9, 6 oz/gal., or 10 oz/gal.--are more sensitive to the quality of the make-up water. Deionized water should be used to prepare these solutions.

14. Good resistance to 100% relative humidity at 125°F was obtained with all the Iridite solutions tested.

15. The resistance of Iridite coated 2219 alloy to outdoor exposure depends largely on the chloride content of the atmosphere. Point Judith, R.I. was the most severe exposure employed, and the results there correlated well with the salt spray accelerated test.

16. For storage environments less severe than Point Judith, the salt spray may be a more selective test than required.

17. Iridite treatments adjusted to produce optimum results on 2219 alloy also function satisfactorily on such other aluminum alloys as 2014, 5052, 6061, and 7075.

18. Sulfuric acid anodizing with a dichromate seal, employed for comparison purposes, was the only treatment to produce the desired corrosion resistance on 2219-T87 alloy.

RECOMMENDATIONS

The following recommendations for the processing of 2219-T87 alloy with a chromate conversion coating are made on the basis of present knowledge, as a result of the work on Contract NAS8-11226.

1. Surface Preparation

a. For optimum chromate coating performance on 2219 alloy, a mechanical surface preparation, such as machining, Scotch Brite brushing, or glass bead blasting, would be preferred. Although some areas on space vehicle parts may be machined, the shape of these parts unfortunately are not conducive to total mechanical preparation. Therefore, chemical treatments must be employed.

b. The first stage on the conversion coating line should be a cleaning operation suitable for removing production and handling soil. Although solvent or vapor degreasing could be employed here, an inhibited alkaline cleaner would seem to be the most feasible.

c. Mill finish material should then be subjected to an oxide removal treatment to dissolve the heavy, thermally formed film encountered on 2219 alloy. Hot sulfuric acid-chromic acid and sulfuric acid-nitric acid solutions or room temperature nitric acid-hydrofluoric solution can be used for this purpose. However, the frequently recommended practice of incorporating a sodium hydroxide etch between two sulfuric acid-chromic acid treatments should be avoided.

d. The deoxidizing operation should be followed by a de-smutting treatment in 50% nitric acid at room temperature.

e. Where possible, machined surfaces should be subjected to a non-etching alkaline cleaning treatment only. Parts with a combination of surfaces will preclude this, however.

f. When machined surfaces are specified, it is desirable to age to final temper prior to the machining operation if possible.

g. Chemically milled surfaces are preferably subjected to a non-etching alkaline cleaning treatment only. Again, this will be precluded by parts with a combination of surfaces.

2. Conversion Coating

a. A chromate conversion coating equivalent to 1.25 oz/gal. Iridite 14-2 at pH 1.5 will provide good salt spray resistance when applied to a mechanically treated surface cleaned in a non-etching alkaline solution.

b. A 1.25 oz/gal. solution adjusted to pH 0.9, a 6 oz/gal. solution, or a 10 oz/gal. solution are more effective than the above standard solution on chemically deoxidized surfaces.

c. The standard 1.25 oz/gal. solution can be prepared with a good grade of tap water. Deionized water should be used for the 1.25 oz/gal. at pH 0.9, 6 oz/gal. and 10 oz/gal. solutions.

d. The standard 1.25 oz/gal. solution should be operated at 85°F for 3 minutes. On chemically deoxidized surfaces, the 1.25 oz/gal. solution at pH 0.9 should be operated at 85°F for 3 minutes, while the 6 oz/gal. and 10 oz/gal. solutions should be operated at 70°F for 3 minutes.

e. On mechanically finished surfaces not followed by subsequent chemical deoxidizing, it is necessary because of the higher surface response, to employ short immersion times in the pH 0.9, the 6 oz/gal., or the 10 oz/gal. solutions.

f. The 10 oz/gal. solution, and to a lesser extent the 6 oz/gal. solution, will require adequate tank venting facilities. In addition, the vendor should be checked for other potential production problems.

3. Preferred Coating Treatment

A 10 oz/gal. Iridite 14-2 solution operated at 70°F will provide the maximum salt spray resistance on 2219-T87 alloy. This is a very expensive coating solution, however, and does not completely eliminate salt spray attack, even for 168 hours. Thus MIL-C-5541a, which specifies 336 hours in the 5% salt spray without corrosion, appears to be entirely unrealistic for this alloy and temper. In view of the difficulty in consistently meeting even the 168 hour specification, it would seem that for production purposes a salt spray requirement might be set at some lower level. This level should not be based on one or two lots of metal, however, and can best be established by a statistical testing of various lots and gages.

In addition, the exposure data obtained in this program indicate that if the storage environment for the coated parts is not exceptionally high in chloride, the usual salt spray test is an unnecessarily severe evaluation. The advantage of an extreme coating treatment to meet a salt spray requirement is frequently not observed in other atmospheres. Accordingly, it is suggested that a 1.25 oz/gal. Iridite 14-2 solution with the pH adjusted to 0.9 with nitric acid will provide adequate protection in chloride-free environments, while also representing a good compromise with respect to salt spray specifications and ease and cost of operation.

A final recommendation, then, is to analyze the anticipated storage atmospheres for space vehicle parts in the light of the exposure results obtained on this contract, for the purpose of selecting the most efficient and economical production coating procedure.

vjm

APPENDIX

INDEX OF TABLES

INDEX OF TABLES
(Cont.)

INDEX OF TABLES
(Cont.)

TABLE 1
COMPOSITION OF 2219 ALLOY TEST SAMPLES

Temper	Gage	Identification	Cu	Fe	Si	Mn	Mg	Ti	V	Zr
-F	0.50"	S-290082	6.10 %	0.19 %	0.10 %	0.28 %	0.01%	0.06 %	0.10 %	0.15 %
-T62	0.50"	S-298551	6.10	0.19	0.10	0.28	0.01	0.06	0.10	0.15
-T37	0.50"	S-290081	6.03	0.13	0.10	0.27	0.01	0.06	0.09	0.15
-T87	0.50"	S-290080	6.13	0.14	0.10	0.27	0.01	0.06	0.09	0.15
-T87	0.50"	S-298548	6.21	0.21	0.11	0.29	0.01	0.06	0.10	0.16
-T87	0.125"	S-298529	6.14	0.21	0.13	0.30	0.02	0.06	0.10	0.15
-T87	0.125"	S-298552	6.32	0.23	0.12	0.29	0.01	0.06	0.10	0.16
-T37	0.50"	S-298779	6.24	0.22	0.11	0.29	0.01	0.07	0.09	0.14
-T87	0.125"	S-298772	6.40	0.21	0.11	0.31	0.01	0.06	0.09	0.14
-T87	0.50"	S-298782	5.95	0.20	0.10	0.28	0.01	0.06	0.10	0.16
-T87	0.50"	S-298778	6.18	0.22	0.11	0.30	0.01	0.07	0.09	0.14
-T87	0.75"	S-298781	6.14	0.21	0.11	0.29	0.01	0.06	0.10	0.15

TABLE 2
PROPERTIES OF 2219 ALLOY TEST SAMPLES

Temper	Gage	Indentification	Rockwell Hard.	Elect. Conduct.	Sol'n Pot.*
-F	0.50"	S-290082	F-67	42.6% IACS	802 mv
-T62	0.50"	S-298551	B-70	----------	791 mv
-T37	0.50"	S-290081	B-71	28.7% IACS	643 mv
-T87	0.50"	S-290080	B-80	32.1% IACS	797 mv
-T87	0.50"	S-298548	B-81	----------	801 mv
-T87	0.125"	S-298529	B-78	----------	802 mv
-T87	0.125"	S-298552	B-80	----------	802 mv
-T37	0.50"	S-298779	----	----------	648 mv
-T87	0.125"	S-298772	----	----------	805 mv
-T87	0.50"	S-298782	----	----------	807 mv
-T87	0.50"	S-298778	----	----------	808 mv
-T87	0.75"	S-298781	----	----------	812 mv

*Against a 0.1 N calomel electrode in $53_g/l$ NaCl, 9 ml/l 30% H_2O_2

TABLE 3
EFFECT OF AGING TIME ON CONVERTING -T37 to -T87 TEMPER

Identification	Gage	Temper	Solution Potential	Tensile	Yield	Elong.
S-298772	0.125"	-T87	805 mv	69,200 psi	57,900 psi	10.0%
S-298779	0.50 "	-T37	648 mv	52,200 psi	44,200 psi	21.0%
+ 8 hrs.; 325°F	0.50 "	Partially Aged	770 mv	67,300 psi	56,300 psi	16.0%
+16 hrs.; 325°F	0.50 "	Aged to -T87	805 mv	68,150 psi	55,900 psi	12.0%
+24 hrs.; 325°F	0.50 "	Aged to -T87	810 mv	68,400 psi	55,900 psi	11.5%
+36 hrs.; 325°F	0.50 "	Aged to -T87	809 mv	68,550 psi	57,000 psi	12.0%
+72 hrs.; 325°F	0.50 "	Aged to -T87	814 mv	66,800 psi	53,800 psi	12.0%

TABLE 4
COMPOSITION OF ALLOYS EXPOSED IN COMPARISON WITH 2219

Alloy	Identification	Cu	Fe	Si	Mn	Mg	Zn	Cr
2014-T6	S-253528	4.52 %	0.33 %	0.84 %	0.80 %	0.46 %	0.05 %	0.03 %
5052-H38	S-65644	0.05	0.22	0.10	0.02	2.43	----	0.24
6061-T6	S-283387	0.23	0.42	0.65	0.09	0.92	0.06	0.20
7075-T6	S-252880	1.69	0.22	0.13	0.07	2.47	5.54	0.24

TABLE 5
CORROSION OF 2219 ALLOY IN 5% CONTINUOUS SALT SPRAY

Alloy	Exp.	Wt. Loss*	Type	Average Depth
Uncoated 2219-T37	1 day	5.1 mg/sqin	Intergranular	0.0046"
	3 day	8.7 mg/sqin	Intergranular	0.0044"
	5 day	12.0 mg/sqin	Intergranular	0.0052"
	7 day	16.1 mg/sqin	Intergranular	0.0044"
Uncoated 2219-T87	1 day	6.9 mg/sqin	Pitting	0.0016"
	3 day	10.3 mg/sqin	Pitting	0.0018"
	5 day	13.6 mg/sqin	Pitting	0.0014"
	7 day	18.2 mg/sqin	Pitting	0.0015"
Iridite Coated 2219-T37	1 day	0.19 mg/sqin	Not Determined	
	3 day	0.25 mg/sqin		
	5 day	0.48 mg/sqin		
	7 day	0.68 mg/sqin		
Iridite Coated 2219-T87	1 day	0.26 mg/sqin	Not Determined	
	3 day	0.42 mg/sqin		
	5 day	0.58 mg/sqin		
	7 day	0.98 mg/sqin		

*Corrosion product was removed by immersion in concentrated nitric acid

TABLE 6

EFFECT OF STORAGE OF IRIDITE COATED 2219-T87 ALLOY ON RESISTANCE TO THE 5% CONTINUOUS SALT SPRAY

Coating Treatment	Aging Period	Results After 168 Hrs. Expos.	Rating
1.25 oz/gal., pH 1.5	2 hours	Almost No Corrosion	A-
	24 hours	Moderate Corrosion	C+
	1 week	Moderate Corrosion	C
	2 weeks	Moderate Corrosion	C
	3 weeks	Moderate Corrosion	C
	4 weeks	Moderate Corrosion	C
1.25 oz/gal., pH 0.9	2 hours	Almost No Corrosion	A-
	24 hours	Mild Corrosion	B-
	1 week	Mild Corrosion	B
	2 weeks	Mild Corrosion	B
	3 weeks	Moderate Corrosion	C
	4 weeks	Moderate Corrosion	C

TABLE 7
QUALITATIVE ANALYSIS* FOR METALLIC ELEMENTS IN IRIDITE 14-2

Cr	(30-50) %
Ba	(10-30) %
K	9 %
Na	5 %
Fe	4 %
Si	3 %
Sr	0.05%
Al	0.04%
Ca	0.01%
Li	0.00%
Mn	0.00%
Mg	0.00%
Ash at 500°C	72.5 %

*Qualitative Analysis: Uncompensated matrix effects render the concentrations given above as broad estimates only. They must be accepted as such and not used or quoted otherwise.

TABLE 8
EFFECT OF SURFACE PREPARATION ON THE IRIDITE COATING WEIGHT OBTAINED ON 2219-T87 ALLOY

	Surface Preparation	Iridite* Wt.
1.	Solvent Cleaned Only.	24.5 mg/sqft
2.	3 min. H_2SO_4-CrO_3** etch at 180°F; 1 min. 5% NaOH etch at 150°F; 1 min. H_2SO_4-CrO_3 etch at 180°F.	20.3 mg/sqft
3.	3 min. H_2SO_4-CrO_3 etch at 180°F; 1 min. 5% NaOH etch at 150°F; 1 min. 50% HNO_3 at 85°F.	20.2 mg/sqft
4.	Machined; Solvent Cleaned.	70.3 mg/sqft
5.	Machined; 3 min. H_2SO_4-CrO_3 etch at 180°F; 1 min. 5% NaOH etch at 150°F; 1 min. H_2SO_4-CrO_3 etch at 180°F.	17.9 mg/sqft
6.	Scotch Brite brushing*** (Minnesota Mining and Manufacturing Co.)	60.5 mg/sqft
7.	Scotch Brite brushing; 3 min. H_2SO_4-CrO_3 etch at 180°F; 1 min. 5% NaOH etch at 150°F; 1 min. H_2SO_4-CrO_3 etch at 180°F.	27.4 mg/sqft

* 1.25 oz/gal. Iridite 14-2, pH 1.4, 85°F, 3 min.
** 100 ml/l 96% H_2SO_4, 35 g/l CrO_3.
***Scotch Brite Flap Brush #50S Fine; 8" diam. wheel, 1740 rpm.

TABLE 9
EFFECT OF SURFACE PREPARATION ON CONTACT RESISTANCE MEASUREMENTS ON 2219-T87 ALLOY

Surface Preparation	Contact Resistance In Microhms			
	Immediate	1 day*	3 days*	7 days*
Scotch Brite	85	94	200	212
Scotch Brite + H_2SO_4-CrO_3 Etch	4	9	93	115
H_2SO_4-CrO_3 Etch + NaOH Etch + H_2SO_4-CrO_3 de-smut	3	10	23	34
H_2SO_4-CrO_3 Etch + NaOH Etch + HNO_3 de-smut	2	16	35	35

*Stored in laboratory atmosphere with free access of air to all surfaces

TABLE 10
SUMMARY OF EFFECTS OF SURFACE PREPARATION ON IRIDITE COATING WEIGHT OBTAINED ON 2219-T87 ALLOY

Surface	Surface Preparation	Coating Weight
Mill Finish	Solvent Cleaned	24.5 mg/sqft
	3 min. H_2SO_4-CrO_3 at 180°F; 1 min. NaOH at 150°F; 3 min. H_2SO_4-CrO_3 at 180°F	20.3 mg/sqft
	5 min. H_2SO_4-CrO_3 at 180°F	30.2 mg/sqft
	3 min. H_2SO_4-HNO_3 at 150°F; Smut removed by wiping	50 mg/sqft
	3 min. H_2SO_4-HNO_3 at 150°F; 30 sec. HNO_3 at R.T.	48 mg/sqft
	3 min. HNO_3-HF at R.T.; Smut removed by wiping	49 mg/sqft
	3 min. HNO_3-HF at R.T.; 30 sec. HNO_3 at R.T.	46 mg/sqft
	2 min. NaOH at 150°F; 30 sec. HNO_3 at R.T.	25.9 mg/sqft
	3 min. NaOH at 150°F; Smut removed by wiping	49.0 mg/sqft
	5 min. H_3PO_4-CrO_3 at 180°F	0.4 mg/sqft
	Scotch Brite Brushing	60.5 mg/sqft
Machined	Solvent Cleaned	70.3 mg/sqft
	3 min. H_2SO_4-CrO_3 at 180°F; 1 min. NaOH at 150°F; 3 min. H_2SO_4-CrO_3 at 180°F	17.9 mg/sqft
	3 min. H_2SO_4-CrO_3 at 180°F	36 mg/sqft
	3 min. H_2SO_4-HNO_3 at 150°F; Smut removed by wiping	45 mg/sqft
	3 min. HNO_3-HF at R.T.; Smut removed by wiping	49 mg/sqft

TABLE 11
EXPOSURE OF IRIDITE COATED GLASS SHOT BLASTED SAMPLES OF 2219-T87 ALLOY TO THE 5% CONTINUOUS SALT SPRAY

Precleaning*	Glass Shot**	Cleaner	Coat. Wt.	Results After 168 Hrs. Expos.	Rating
Inhib. Clean., H_2SO_4-CrO_3, HNO_3	——	---	30 mg/ft^2	Moderate Corrosion	C
Inhib. Clean., H_2SO_4-CrO_3, HNO_3	MSP (-35 + 60)	Inhib. Alk.	48 mg/ft^2	Moderate Corrosion	C
None	MSL (-200 + 325)	Inhib. Alk.	65 mg/ft^2	Mild Corrosion	B+

---

* 5% Inhibited Alk. Cleaner, 180°F, 3 min.; 10% vol. 96% H_2SO_4, 3.5% CrO_3, 180°F 3 min.; 50% HNO_3, 80°F, 30 sec.

** Microbeads Division, Cataphote Corporation
P. O. Box 2369, Jackson, Mississippi

TABLE 12
POTENTIAL MEASUREMENTS ON 2219-T87 ALLOY COUPLED TO OTHER METALS IN IRIDITE 14-2 SOLUTION

Metal	Open Circuit Potential*		Coupled To 2219-T87*	
	Initial	After 3 Min.	Initial	After 3 Min.
2219-T87	-500 mv	-519 mv	---	---
99.99% Al	-500	-540	-500 mv	-510 mv
Stainless Steel	+589	+110	-502	-509
Copper	+441	+162	-462	-490
Graphite	+757	+715	+410	+415

* Versus Standard Calomel Electrode

TABLE 13
CURRENT FLOW WITH 2219-T87 ALLOY COUPLED TO OTHER METALS IN IRIDITE 14-2 SOLUTION

Couple	0	0.5 Min.	1 Min.	1.5 Min.	2 Min.	2.5 Min.	3 Min.
2219-T87 99.99% Al	Fluctuates between 0 and 0.5 to 0.25 ma/sqin						
2219-T87 Stainless Steel	1.0 ma/sqin	0.1 ma/sqin	0.09 ma/sqin	0.07 ma/sqin	0.07 ma/sqin	0.07 ma/sqin	0.06 ma/sqin
2219-T87 Copper	7.0	1.7	1.4	1.3	1.1	1.0	0.93
2219-T87 Graphite	11.5	10.5	6.2	5.0	4.4	4.3	4.3

TABLE 14

EXPOSURE OF HEAVY IRIDITE COATINGS TO THE 5% CONTINUOUS SALT SPRAY FOR 168 HOURS

Coating Solution	Time	Coating Wt.	Results After 168 Hrs. Exposure	Rating
10 oz/gal. at 70°F	3 min.	99 mg/sqft	Mild Corrosion	B
	4 min.	105 mg/sqft	Mild Corrosion	B-
	6 min.	122 mg/sqft	Mild Corrosion	B-
10 oz/gal. at 50°F	3 min.	69 mg/sqft	Mild Corrosion	B+
	4 min.	81 mg/sqft	Mild Corrosion	B
	6 min.	104 mg/sqft	Mild Corrosion	B
1.25 oz/gal. at 85°F	3 min.	23 mg/sqft	Moderate Corrosion	C

TABLE 15
EFFECT OF COATING SOLUTION COMPOSITION ON THE RESISTANCE OF IRIDITE COATED 2219-T87 ALLOY TO THE 5% SALT SPRAY

Solution Composition	Coating Weight	Results After 168 Hrs. Exp.***	Ratin
9.4 g/l Iridite 14-2* (1.25 oz/gal.)	19 mg/sq.ft.	Moderate Corrosion	C
75 g/l Iridite 14-2** (10 oz/gal.)	71 mg/sq.ft.	Mild Corrosion	B-
5 g/l CrO_3, 1 g/l $K_3Fe(CN)_6$, 1.4 g/l Na_2SiF_6*	26 mg/sq.ft.	Moderate Corrosion	C-
5 g/l CrO_3, 1 g/l $K_3Fe(CN)_6$, 11 g/l Na_2SiF_6**	53 mg/sq.ft.	Moderate Corrosion	C
40 g/l CrO_3, 8 g/l $K_3Fe(CN)_6$, 11 g/l Na_2SiF_6**	61 mg/sq.ft.	Mild Corrosion	B
40 g/l CrO_3, 8 g/l $K_3Fe(CN)_6$, 11 g/l Na_2SiF_6, 15.2 g/l $Ba(NO_3)_2$**	81 mg/sq.ft.	Mild Corrosion	B-

* Coated 3 min. at 85°F.

** Coated 3 min. at 70°F.

*** Exposed to the salt spray about 5 days after preparation.

TABLE 16

EFFECT OF STORAGE ON LEACHABILITY OF HEXAVALENT CHROMIUM FROM IRIDITE COATED 2219-T87 ALLOY

Coating Solution	Storage Interval	Hexavalent Chromium Leached From 36 Sq.In. 1st Day	2nd Day	3rd Day
1.25 oz/gal., pH 1.5	2 Hours	0.22 mg	0.05 mg	0.01 mg
	65 Hours	0.14	0.05	0.02
	10 Days	0.07	0.06	0.03
1.25 oz/gal., pH 0.9	2 Hours	0.68	0.09	0.03
	65 Hours	0.48	0.10	0.04
	10 Days	--	0.17	0.07
10 oz/gal.	2 Hours	1.45	0.16	0.04
	65 Hours	1.23	0.32	0.08
	10 Days	0.63	0.52	0.26

TABLE 17
LOSS IN YELLOWNESS OF IRIDITE COATED 2219-T87 ALLOY EXPOSED TO THE SALT SPRAY FOR VARIOUS TIMES

Cleaning Treatment	Coating Treatment	Days In Salt Spray	Change In Yellowness*
Inhib. Alk. Clean.; 180°F; 3 min. 100 ml/l 96% H_2SO_4, 35 g/l CrO_3; 180°F; 3 min. 50% HNO_3; 80°F; 30 sec.	10 oz/gal.; 70°F; 3 min.	1 day	- 32.6%
		2 days	- 51.1%
		3 days	- 53.6%
		4 days	- 59.5%
		5 days	- 68.0%
		6 days	- 64.6%
		7 days	- 78.1%

* Measured on Color-Eye instrument, Instrument Development Laboratories, Inc., Attleboro, Mass.

TABLE 18

RELATIVE CORROSION WEIGHT LOSS OF IRIDITE COATED 2219-T87 ALLOY EXPOSED TO THE SALT SPRAY FOR VARIOUS TIMES

Cleaning Treatment	Coating Treatment	Time In Salt Spray	Weight Loss 3" x 6" Sample
Inhib. Alk. Clean.; 180°F; 3 min. 100 ml/l 96% H_2SO_4, 35 g/l CrO_3; 180°F; 3 min. 50% HNO_3; 80°F; 30 sec.	10 oz/gal.; 70°F; 3 min.	1 day	5.7 mg
		2 days	11.8 mg
		3 days	13.5 mg
		4 days	14.4 mg
		5 days	15.1 mg
		6 days	13.9 mg
		7 days	16.9 mg

NOTE: 10 oz/gal. Iridite coating weight per 3" x 6" surface = 11.7 mg

TABLE 19
COMPARISON OF DEOXIDIZING TREATMENTS ON IRIDITE COATED 2219-T87 ALLOY EXPOSED TO THE SALT SPRAY

Deoxidizing Treatment	Coating Treatment	Results After 168 Hrs.	Rating
H_2SO_4-CrO_3; 180°F; 3 min. 50% HNO_3; 80°F; 30 sec.	10 oz/gal.; 70°F; 3 min.	Moderate Corrosion	C+
HNO_3-$Na_2Cr_2O_7$-NH_4HF_2; 80°F; 30 min. 50% HNO_3; 80°F; 30 sec.	10 oz/gal.; 70°F; 3 min.	Moderate Corrosion	C
100 ml/l H_2SO_4-50 ml/l HNO_3; 150°F; 3 min. 50% HNO_3; 80°F; 30 sec.	10 oz/gal.; 70°F; 3 min.	Mild Corrosion	B-
100 ml/l HNO_3-10 ml/l HF; 80°F; 3 min. 50% HNO_3; 80°F; 30 sec.	10 oz/gal.; 70°F; 3 min.	Moderate Corrosion	C+
3M Scotchbrite	10 oz/gal.; 70°F; 3 min.	Mild Corrosion	B
H_2SO_4-CrO_3; 180°F; 3 min. 50% HNO_3; 80°F; 30 sec.	1.25 oz/gal.; 85°F; 3 min.	Moderate Corrosion	C-

TABLE 20
EFFECT OF ARTIFICIAL AGING TIME ON 2219 ALLOY ON SALT SPRAY RESISTANCE AFTER IRIDITE COATING

Aging Treatment -T37 to -T87	Coating Treatment	Results After 168 Hrs. Exposure*	Rating
8 Hours at 325°F	1.25 oz/gal.; 85°F; 3 min.	Almost No Corrosion	A-
	10 oz/gal.; 70°F; 3 min.	Almost No Corrosion	A
16 Hours at 325°F	1.25 oz/gal.; 85°F; 3 min.	Mild Corrosion	B-
	10 oz/gal.; 70°F, 3 min.	Mild Corrosion	B
24 Hours at 325°F	1.25 oz/gal.; 85°F; 3 min.	Moderate Corrosion	C
	10 oz/gal.; 70°F; 3 min.	Mild Corrosion	B-
32 Hours at 325°F	1.25 oz/gal.; 85°F; 3 min.	Mild Corrosion	B-
	10 oz/gal.; 70°F; 3 min.	Mild Corrosion	B-
64 Hours at 325°F	1.25 oz/gal.; 85°F; 3 min.	Moderate Corrosion	C
	10 oz/gal.; 70°F; 3 min.	Moderate Corrosion	C
Plant Produced -T87 S-298772	1.25 oz/gal.; 85°F; 3 min.	Moderate Corrosion	C-
	10 oz/gal.; 70°F; 3 min.	Moderate Corrosion	C-

* Exposed 24 hours after coating

TABLE 21
SALT SPRAY EXPOSURE OF ALLOYS OTHER THAN 2219 WHEN COATED IN 10 OZ/GAL. IRIDITE 14-2

Alloy	Coating Time	Coating Weight	Results After 168 Hours	Rating
2014-T6	1 min.	76 mg/sqft	No Corrosion	A
5052-H38	30 sec.	76 mg/sqft	No Corrosion	A
6061-T6	30 sec.	75 mg/sqft	No Corrosion	A
7075-T6	1 min.	39 mg/sqft	Very Mild Corrosion	B+

TABLE 22
EFFECT OF ACID TREATMENT AND RE-COATING ON SALT SPRAY RESISTANCE OF IRIDITE COATED 2219-T87 ALLOY

First Coating*	Acid Treatment	Second Coating	Results After 168 Hours Exposure**	Rating
1.25 oz/gal., 85°F, 3 min.	None	1.25 oz/gal., 85°F, 3 min.	Moderate Corrosion	C-
10 oz/gal., 70°F, 3 min.	None	10 oz/gal., 70°F, 3 min.	Mild Corrosion	B
1.25 oz/gal., 85°F, 3 min.	50% HNO_3, 80°F, 1 min.	1.25 oz/gal., 85°F, 3 min.	Moderate Corrosion	C-
10 oz/gal., 70°F, 3 min.	50% HNO_3, 80°F, 1 min.	10 oz/gal., 70°F, 3 min.	Mild Corrosion	B
1.25 oz/gal., 85°F, 3 min.	50% HNO_3, 80°F, 5 min.	1.25 oz/gal., 85°F, 3 min.	Moderate Corrosion	C-
10 oz/gal., 70°F, 3 min.	50% HNO_3, 80°F, 5 min.	10 oz/gal., 70°F, 3 min.	Mild Corrosion	B
1.25 oz/gal., 85°F, 3 min.	50% HNO_3, 180°F, 1 min.	1.25 oz/gal., 85°F, 3 min.	Moderate Corrosion	C
10 oz/gal., 70°F, 3 min.	50% HNO_3, 180°F, 1 min.	10 oz/gal., 70°F, 3 min.	Mild Corrosion	B
1.25 oz/gal., 85°F, 3 min.	None	None	Moderate Corrosion	C
10 oz/gal., 70°F, 3 min.	None	None	Mild Corrosion	B

* First coating aged for 72 hours before further treatment.

** Exposed to the 5% salt spray 48 hours after final coating.

TABLE 23
EFFECT OF $Na_2Cr_2O_7$ SEALING CONDITIONS ON THE RESISTANCE OF IRIDITE COATED 2219-T87 ALLOY TO THE 5% SALT SPRAY

Coating Treatment	Sealing Treatment	Sealed	Results After 168 Hrs. Exp.*	Rating
1.25 oz/gal.; 85°F; 3 min.	100 g/l; 5 min.; R.T.	Immediately	Moderate Corrosion	C-
	100 g/l; 5 min.; R.T.	After 18 hrs.	Moderate Corrosion	C+
	100 g/l; 5 min.; 180°F	Immediately	Mild Corrosion	B
	100 g/l; 5 min.; 180°F	After 18 hrs.	Moderate Corrosion	C-
	500 g/l; 5 min.; R.T.	Immediately	Moderate Corrosion	C
	500 g/l; 5 min.; R.T.	After 18 hrs.	Moderate Corrosion	C-
	500 g/l; 5 min.; 180°F	Immediately	Moderate Corrosion	C
	500 g/l; 5 min.; 180°F	After 18 hrs.	Moderate Corrosion	C
	Unsealed (Control)		Moderate Corrosion	C-
10 oz/gal.; 70°F; 3 min.	100 g/l; 5 min.; R.T.	Immediately	Moderate Corrosion	C
	100 g/l; 5 min.; R.T.	After 18 hrs.	Moderate Corrosion	C
	100 g/l; 5 min.; 180°F	Immediately	Mild Corrosion	B-
	100 g/l; 5 min.; 180°F	After 18 hrs.	Moderate Corrosion	C
	500 g/l; 5 min.; R.T.	Immediately	Moderate Corrosion	C
	500 g/l; 5 min.; R.T.	After 18 hrs.	Moderate Corrosion	C
	500 g/l; 5 min.; 180°F	Immediately	Moderate Corrosion	C
	500 g/l; 5 min.; 180°F	After 18 hrs.	Moderate Corrosion	C
	Unsealed (Control)		Moderate Corrosion	C

* Exposed 48 hours after sealing

TABLE 24
EFFECT OF SEALING TREATMENTS ON THE SALT SPRAY RESISTANCE OF IRIDITE COATED 2219-T87 ALLOY

Coating Solution	Sealing Treatment	Results After 168 Hrs. Expos.	Rating
1.25 oz/gal., pH 1.5	No Seal	Moderate Corrosion	C
	Dist. H_2O, 30 sec., 190°F	Severe Corrosion	D
	Dist. H_2O, 1 min., 190°F	Severe Corrosion	D-
	Dist. H_2O, 5 min., 190°F	Severe Corrosion	D
	2.5% Kasil #1, 5 min., 180°F; 5% $K_2Cr_2O_7$, 5 min., 180°F	Mild Corrosion	B
	2.5% Kasil #1, 2.5% K_2CrO_4, 5 min., 180°F	Mild Corrosion	B
	5% $K_2Cr_2O_7$, 5 min., 180°F	Moderate Corrosion	C
	0.001% CrO_3, 1 min., 190°F	Moderate Corrosion	C
1.25 oz/gal., pH 0.9	No Seal	Mild Corrosion	B-
	Dist. H_2O, 30 sec., 190°F	Moderate Corrosion	C
	Dist. H_2O, 1 min., 190°F	Moderate Corrosion	C
	Dist. H_2O, 5 min., 190°F	Severe Corrosion	D
	2.5% Kasil #1, 5 min., 180°F; 5% $K_2Cr_2O_7$, 5 min., 180°F	Mild Corrosion	B+

TABLE 24

EFFECT OF SEALING TREATMENTS ON THE SALT SPRAY RESISTANCE OF IRIDITE COATED 2219-T87 ALLOY

(Continued)

Coating Solution	Sealing Treatment	Results After 168 Hrs. Expos.	Rating
1.25 oz/gal., pH 0.9	2.5% Kasil #1, 2.5% K_2CrO_4, 5 min., 180°F	Mild Corrosion	B
	5% $K_2Cr_2O_7$, 5 min., 180°F	Moderate Corrosion	C
	0.001% CrO_3, 1 min., 190°F	Moderate Corrosion	C

TABLE 25

EFFECT OF SEALING ON THE RESISTANCE OF VARIOUS IRIDITE COATINGS ON 2219-T87 ALLOY TO THE 5% CONTINUOUS SALT SPRAY

Coating Treatment	Sealing Treatment*	Results After 168 Hours Exposure	Rating
1.25 oz/gal., pH 1.5, 85°F, 3 min.	Unsealed	Moderate Corrosion	C
	Sealed	Mild Corrosion	B
1.25 oz/gal., pH 0.9, 85°F, 3 min.	Unsealed	Moderate Corrosion	C
	Sealed	Mild Corrosion	B
10 oz/gal., 50°F, 4 min.	Unsealed	Mild Corrosion	B
	Sealed	No Corrosion	A
10 oz/gal., 70°F, 4 min.	Unsealed	Mild Corrosion	B
	Sealed	No Corrosion	A

* 25 ml/1 Kasil #1, 25 g/1 K_2CrO_4; 180°F; 5 min.

2219-T87 Alloy S-298772

TABLE 26
EFFECT OF IRIDITE COATING AND SEALING TREATMENTS ON ADHESION OF ZINC CHROMATE PRIMER TO 2219-T87 ALLOY

Coating Treatment	Sealed*	Zinc Chromate Primer Adhesion	
		As Coated**	After 72 Hrs. In 0.5% NaCl***
1.25 oz/gal., pH 1.5, 85°F, 3 min.	No	Passed	Passed
1.25 oz/gal., pH 1.5, 85°F, 3 min.	Yes	Passed	Failed
1.25 oz/gal., pH 0.9, 85°F, 3 min.	No	Passed	Passed
10 oz/gal., 50°F, 4 min.	No	Passed	Passed
10 oz/gal., 70°F, 4 min.	No	Passed	Passed
10 oz/gal., 70°F, 4 min.	Yes	Passed	Failed (Blistered)

* Sealed for 5 min. at 180°F in 25 ml/l Kasil #1, 25 g/l K_2CrO_4 approximately 18 hours after coating.

** Cross-hatched with Gitterschnitt-Pruefer tool (F. Senninger, Berlin Spandau, Germany) and tested with Scotch Tape.

*** Tested immediately after removal from NaCl solution with Scotch Tape without cross-hatching.

TABLE 27
EFFECT OF ZINC CHROMATE TYPE SEALING ON SALT SPRAY RESISTANCE OF IRIDITE COATED 2219-T87 ALLOY

Coating Treatment	Sealing Treatment	Results After 168 Hours	Rating
1.25 oz/gal.; 85°F; 3 min.	None	Moderate Corrosion	C
10 oz/gal.; 70°F; 3 min.	None	Very Mild Corrosion	B+
1.25 oz/gal.; 85°F; 3 min.	20 g/l CrO_3-5 g/l ZnO; pH 1.4, 80°F; 3 min. No rinse after seal	Moderate Corrosion	C
10 oz/gal.; 70°F; 3 min.		Moderate Corrosion	C+
1.25 oz/gal.; 85°F; 3 min.	20 g/l CrO_3-10 g/l ZnO; pH 5.6; 80°F; 3 min. No rinse after seal	Moderate Corrosion	C+
10 oz/gal.; 70°F; 3 min.		Moderate Corrosion	C+
1.25 oz/gal.; 85°F; 3 min.	20 g/l $ZnSO_4 \cdot 7H_2O$; pH 5.2; 80°F; 3 min. No rinse before but rinse after seal	Moderate Corrosion	C
10 oz/gal.; 70°F; 3 min.		Mild Corrosion	B
1.25 oz/gal.; 85°F; 3 min.	Aged 18 hrs. - 20 g/l CrO_3, 5 g/l ZnO; 150°F; 3 min.; No rinse after seal	Moderate Corrosion	C
10 oz/gal.; 70°F; 3 min.		Mild Corrosion	B-
1.25 oz/gal.; 85°F; 3 min.	Aged 18 hrs. - 20 g/l CrO_3, 10 g/l ZnO; 150°F; 3 min.; No rinse after seal	Moderate Corrosion	C
10 oz/gal.; 70°F; 3 min.		Mild Corrosion	B-
1.25 oz/gal.; 85°F; 3 min.	Aged 18 hrs. - 20 g/l CrO_3, 5 g/l ZnO; 150°F; 3 min.; Rinse	Moderate Corrosion	C
10 oz/gal.; 70°F; 3 min.		Mild Corrosion	B-
1.25 oz/gal.; 85°F; 3 min.	Aged 18 hrs. - 20 g/l CrO_3, 10 g/l ZnO; 150°F; 3 min.; Rinse	Mild Corrosion	B-
10 oz/gal.; 70°F; 3 min.		Almost No Corrosion	A-
1.25 oz/gal.; 85°F; 3 min.	Aged 18 hrs. - 20 g/l $ZnSO_4 \cdot 7H_2O$; 150°F; 3 min.; Rinse	Mild Corrosion	B-
10 oz/gal.; 70°F; 3 min.		Mild Corrosion	B-

TABLE 28
EFFECT OF IMMEDIATE SEALING ON IRIDITE COATED 2219-T87 ALLOY EXPOSED TO THE 5% CONTINUOUS SALT SPRAY

Coating Treatment	Sealing Treatment	Results After 168 Hrs.*	Rating
1.25 oz/gal.	2% CrO_3, 1% ZnO; 75°F; 3 min.	Moderate Corrosion	C
10 oz/gal.		Moderate Corrosion	C
1.25 oz/gal.	2% CrO_3, 1% ZnO; 150°F; 3 min.	Moderate Corrosion	C
10 oz/gal.		Mild Corrosion	B
1.25 oz/gal.	5% CrO_3, 2.5% ZnO; 75°F; 3 min.	Moderate Corrosion	C-
10 oz/gal.		Moderate Corrosion	C
1.25 oz/gal.	5% CrO_3, 2.5% ZnO; 150°F; 3 min.	Moderate Corrosion	C
10 oz/gal.		Mild Corrosion	B-
1.25 oz/gal.	10% CrO_3, 5% ZnO; 75°F; 3 min.	Severe Corrosion	D
10 oz/gal.		Moderate Corrosion	C+
1.25 oz/gal.	10% CrO_3, 5% ZnO; 150°F; 3 min.	Moderate Corrosion	C
10 oz/gal.		Mild Corrosion	B+
1.25 oz/gal.	Unsealed - Control	Moderate Corrosion	C
10 oz/gal.		Mild Corrosion	B-

* Exposed to the 5% NaCl continuous spray 48 hours after preparation

TABLE 29
EFFECT OF DELAYED SEALING ON IRIDITE COATED 2219-T87 ALLOY EXPOSED TO THE 5% CONTINUOUS SALT SPRAY

Coating Treatment	Sealing Treatment*	Results After 168 Hrs.**	Rating
1.25 oz/gal.	2% CrO_3, 1% ZnO; 75°F; 3 min.	Moderate Corrosion	C-
10 oz/gal.		Mild Corrosion	B+
1.25 oz/gal.	2% CrO_3, 1% ZnO; 150°F; 3 min.	Moderate Corrosion	C
10 oz/gal.		Mild Corrosion	B
1.25 oz/gal.	5% CrO_3, 2.5% ZnO; 75°F; 3 min.	Moderate Corrosion	C
10 oz/gal.		Almost No Corrosion	A-
1.25 oz/gal.	5% CrO_3, 2.5% ZnO; 150°F; 3 min.	Moderate Corrosion	C
10 oz/gal.		Mild Corrosion	B+
1.25 oz/gal.	10% CrO_3, 5% ZnO; 75°F; 3 min.	Moderate Corrosion	C
10 oz/gal.		Almost No Corrosion	A-
1.25 oz/gal.	10% CrO_3, 5% ZnO; 150°F; 3 min.	Moderate Corrosion	C
10 oz/gal.		Mild Corrosion	B
1.25 oz/gal.	Unsealed - Control	Moderate Corrosion	C
10 oz/gal.		Mild Corrosion	B

* Sealed 18 hours after coating.

**Exposed to the 5% NaCl continuous spray 1 week after sealing.

TABLE 30
EFFECT OF SEALING ON ZINC CHROMATE PRIMER ADHESION ON IRIDITE COATED 2219-T87 ALLOY

Coating Treatment	Sealing Treatment*	Zinc Chromate Primer Adhesion	
		As Coated**	After Immersion***
10 oz/gal.; 70°F; 3 min.	Unsealed - Control	Passed	Passed
	Immed. Seal. - 75°F	Passed	Passed
	Immed. Seal. - 150°F	Passed	Slight pick-off
	Delayed Seal. - 75°F	Passed	Passed
	Delayed Seal. - 150°F	Passed	Slight pick-off

* Sealed 3 minutes in 100 g/l CrO_3, 50 g/l ZnO. Delayed sealing occurred 18 hours after coating.

** Cross-hatched with Gitterschnitt-Pruefer tool (F. Senninger, Berlin Spandau, Germany) and tested with Scotch Tape.

*** Immersed for 72 hours in 0.5% NaCl solution at room temperature and tested immediately with Scotch Tape and without cross-hatching.

TABLE 31
EFFECT OF USAGE ON IRIDITE COATING TREATMENTS FOR 2219-T87 ALLOY

Coating Solution	Condition	CrO_3	pH	Coating Weight
1.25 oz/gal.	Initial	4.90 g/l	1.5	33 mg/sq.ft.
	After Use	4.76 g/l	1.6	30 mg/sq.ft.
	Add 0.25 g/l Iridite	5.00 g/l	1.6	29 mg/sq.ft.
1.25 oz/gal. (pH 0.9)	Initial	4.96 g/l	0.9	65 mg/sq.ft.
	After Use	4.86 g/l	1.0	55 mg/sq.ft.
	Add 0.25 g/l Iridite	5.04 g/l	1.0	69 mg/sq.ft.
6 oz/gal.	Initial	---	0.9	72 mg/sq.ft.
	After Use	25.4 g/l	1.1	66 mg/sq.ft.
	Add 1.2 g/l Iridite	26.2 g/l	1.0	75 mg/sq.ft.
10 oz/gal.	Initial	42.3 g/l	0.8	105 mg/sq.ft.
	After Use	41.1 g/l	0.9	91 mg/sq.ft.
	Add 2.0 g/l Iridite	42.1 g/l	0.9	109 mg/sq.ft.

TABLE 32
EFFECT OF COATING SOLUTION USAGE ON SALT SPRAY RESISTANCE OF IRIDITE TREATED 2219-T87 ALLOY

Coating Solution	Condition	Results After 168 Hours	Rating
1.25 oz/gal.	Initial	Moderate Corrosion	C-
	Used	Moderate Corrosion	C-
	Adjusted	Moderate Corrosion	C-
1.25 oz/gal. (pH 0.9)	Initial	Moderate Corrosion	C
	Used	Moderate Corrosion	C
	Adjusted	Moderate Corrosion	C
6 oz/gal.	Initial	__________	--
	Used	Moderate Corrosion	C
	Adjusted	Moderate Corrosion	C
10 oz/gal.	Initial	Mild Corrosion	B
	Used	Moderate Corrosion	C
	Adjusted	Moderate Corrosion	C

TABLE 33
ANALYSIS OF TAP WATER FOR PILOT PLANT SCALE TEST

pH	7.6
Total Solids, 105°C	280 ppm
Total Solids, 500°C	240
Total Hardness (EDTA) as $CaCO_3$	149
Chloride	22
Sulfate	128
Calcium (EDTA)	48
Magnesium (EDTA)	7

TABLE 34
IRIDITE SOLUTION IN PILOT PLANT TEST

Use	Cr^{+6}	CrO_3	Aluminum			Coating Wt.
Initial	23.0 g/l	44.3 g/l	0.001 g/l	or	0.95 g/tank	174 mg/ft^2
1 ft^2/gal	23.0	44.3	0.008		7.6	170
2	23.0	44.3	0.013		12.3	171
3	22.7	43.7	0.018		17.1	161
4	22.5	43.3	0.023		21.8	164
5	22.6	43.5	0.028		26.6	171
6	22.5	43.3	0.033		31.4	161
7	22.6	43.5	0.039		37.0	160
8	22.6	43.5	0.042		39.8	170
9	22.6	43.5	0.046		43.6	153
10	22.4	43.1	0.051		48.5	141

TABLE 35
SALT SPRAY EXPOSURE OF PILOT PLANT TEST SAMPLES

Gage	Iridite	Identification	Results After 168 Hrs.	Rating
0.125"	10 oz/gal.	Initial	Mild Corrosion	B-
		After 1 ft^2/gal.	Mild Corrosion	B-
		2 ft^2/gal.	Mild Corrosion	B-
		3 ft^2/gal.	Mild Corrosion	B-
		4 ft^2/gal.	Mild Corrosion	B-
		5 ft^2/gal.	Mild Corrosion	B-
		6 ft^2/gal.	Mild Corrosion	B-
		7 ft^2/gal.	Mild Corrosion	B-
		8 ft^2/gal.	Mild Corrosion	B-
		9 ft^2/gal.	Mild Corrosion	B-
		10 ft^2/gal.	Mild Corrosion	B-
0.125"	1.25 oz/gal.	Control	Moderate Corrosion	C-
0.50"	10 oz/gal.	Initial	Mild Corrosion	B
		After 1 ft^2/gal.	Mild Corrosion	B
		2 ft^2/gal.	Mild Corrosion	B
		3 ft^2/gal.	Mild Corrosion	B-
		4 ft^2/gal.	Mild Corrosion	B-
		5 ft^2/gal.	Mild Corrosion	B
		6 ft^2/gal.	Mild Corrosion	B
		7 ft^2/gal.	Mild Corrosion	B
		8 ft^2/gal.	Mild Corrosion	B
		9 ft^2/gal.	Mild Corrosion	B
		10 ft^2/gal.	Mild Corrosion	B
0.50"	1.25 oz/gal.	Control	Moderate Corrosion	C

TABLE 36
IRIDITE COATING WEIGHTS ON ALLOYS EXPOSED IN COMPARISON WITH 2219

Surface Preparation	Iridite Coating	2014	5052	6061	7075
3 min. Inhib. Clean., 180°F 3 min. H_2SO_4-CrO_3, 180°F 30 sec. HNO_3, 80°F	1.25 oz/gal., pH 1.5, 3 min., 85°F	35 mg/sqft	61 mg/sqft	45 mg/sqft	20 mg/sqft
3M Scotch Brite Brush 3 min. Inhib. Clean., 180°F	1.25 oz/gal., pH 1.5, 3 min., 85°F	42 mg/sqft	22 mg/sqft	29 mg/sqft	49 mg/sqft
3 min. Inhib. Clean., 180°F 3 min. H_2SO_4-CrO_3, 180°F 30 sec. HNO_3, 80°F	1.25 oz/gal., pH 0.9 1 min., 85°F	53 mg/sqft	94 mg/sqft	82 mg/sqft	50 mg/sqft
3 min. Inhib. Clean., 180°F 3 min. H_2SO_4-CrO_3, 180°F 30 sec. HNO_3, 80°F	6 oz/gal., pH 0.7 1 min., 70°F	49 mg/sqft	89 mg/sqft	97 mg/sqft	*

*Coating chalky; weight not reliable because of tendency to wash off during rinsing.

TABLE 37
EXPOSURE SAMPLES OF 2014, 5052, 6061, AND 7075 ALLOYS*

Coating Treatment	Salt Spray	Humidity	New Ken.	Pt. Judith	Florida
1.25 oz/gal., pH 1.5, 85°F, 3 min.	-1,-2,-3	-4,-5,-6	-7,-8,-9	-10,-11,-12	-13,-14,-15
Above with Scotch Brite Prep.	-18,-19,-20	-21,-22,-23	-24,-25,-26	-27,-28,-29	-30,-31,-32
1.25 oz/gal., pH 0.9, 85°F, 1 min.	-35,-36,-37	-38,-39,-40	-41,-42,-43	-44,-45,-46	-47,-48,-49
6 oz/gal., pH 0.7, 70°F, 1 min.	-52,-53,-54	-55,-56,-57	-58,-59,-60	-61,-62,-63	-64,-65,-66

*2014-T6 - S-253528
5052-H38 - S-65644
6061-T6 - S-283387
7075-T6 - S-252880

TABLE 38
SALT SPRAY EVALUATION TEST NO. 1 - 5052 AND 7075 ALLOYS

Alloy	Coating	Identification	Results After 168 Hours Exposure	Average Rating
5052-H38	1.25 oz/gal., pH 1.5	S-65644-1	No Corrosion	A
		-2	No Corrosion	(No Corrosion)
		-3	No Corrosion	
	Scotch Brite + Above	S-65644-18	No Corrosion	A
		-19	No Corrosion	
		-20	One Stained Area	
	1.25 oz/gal., pH 0.9	S-65644-35	No Corrosion	A
		-36	No Corrosion	
		-37	No Corrosion	
	6 oz/gal., pH 0.7	S-65644-52	No Corrosion	A
		-53	No Corrosion	
		-54	No Corrosion	
7075-T6	1.25 oz/gal., pH 1.5	S-252880-1	Mild Corrosion	B
		-2	Mild Corrosion	(Mild Corrosion)
		-3	Mild Corrosion	
	Scotch Brite + Above	S-252880-18	Dark Stain. Mild Corrosion	B
		-19	Similar to #18 but less extensive	
		-20	No Corrosion	
	1.25 oz/gal., pH 0.9	S-252880-35	No Corrosion	A
		-36	No Corrosion	
		-37	No Corrosion	
	6 oz/gal., pH 0.7	S-252880-52	Mild Corrosion	B
		-53	Mild Corrosion	
		-54	Mild Corrosion	

TABLE 39
SALT SPRAY EVALUATION TEST NO. 2 - 2014 AND 6061 ALLOYS

Alloy	Coating	Identification	Results After 168 Hrs. Exp.	Rating
2014-T6	1.25 oz/gal., pH 1.5	S-253528-1	Mild Corrosion	B
		-2	Mild Corrosion	
		-3	Mild Corrosion	
	Scotch Brite + Above	S-253528-18	No Corrosion	A-
		-19	Very Mild Corrosion	
		-20	Very Mild Corrosion	
	1.25 oz/gal., pH 0.9	S-253528-35	No Corrosion	A-
		-36	Very Mild Corrosion	
		-37	Very Mild Corrosion	
	6 oz/gal., pH 0.7	S-253528-52	No Corrosion	A
		-53	No Corrosion	
		-54	No Corrosion	
6061-T6	1.25 oz/gal., pH 1.5	S-283387-1	No Corrosion	A
		-2	No Corrosion	
		-3	No Corrosion	
	Scotch Brite + Above	S-283387-18	No Corrosion	A
		-19	No Corrosion	
		-20	No Corrosion	
	1.25 oz/gal., pH 0.9	S-283387-35	No Corrosion	A
		-36	No Corrosion	
		-37	No Corrosion	
	6 oz/gal., pH 0.7	S-283387-52	No Corrosion	A
		-53	No Corrosion	
		-54	No Corrosion	

TABLE 40

SALT SPRAY EVALUATION CONTINUED TO 336 HOURS - 5052 and 7075 ALLOYS

Alloy	Coating	Identification	Results After 336 Hrs. Exposure	Rating
5052-H38	1.25 oz/gal., pH 1.5	S-65644-1	No Corrosion	A
		-2	No Corrosion	
		-3	No Corrosion	
	Scotch Brite + 1.25 oz/gal., pH 1.5	S-65644-18	No Corrosion	A
		-19	No Corrosion	
		-20	No Corrosion	
	1.25 oz/gal., pH 0.9	S-65644-35	No Corrosion	A
		-36	No Corrosion	
		-37	No Corrosion	
	6 oz/gal., pH 0.7	S-65644-52	No Corrosion	A
		-53	No Corrosion	
		-54	No Corrosion	
7075-T6	1.25 oz/gal., pH 1.5	S-252880-1	Severe Corrosion	D
		-2	Severe Corrosion	
		-3	Severe Corrosion	
	Scotch Brite + 1.25 oz/gal., pH 1.5	S-252880-18	Severe Corrosion	C-
		-19	Moderate Corrosion	
		-20	Moderate Corrosion	
	1.25 oz/gal., pH 0.9	S-252880-35	Mild Corrosion	B
		-36	Mild Corrosion	
		-37	Mild Corrosion	
	6 oz/gal., pH 0.7	S-252880-52	Severe Corrosion	D
		-53	Severe Corrosion	
		-54	Severe Corrosion	

TABLE 41

SALT SPRAY EVALUATION CONTINUED TO 336 HOURS - 2014 and 6061 ALLOYS

Alloy	Coating	Identification	Results After 336 Hrs. Exposure	Rating
2014-T6	1.25 oz/gal., pH 1.5	S-253528-1	Severe Corrosion	D
		-2	Severe Corrosion	
		-3	Severe Corrosion	
	Scotch Brite + 1.25 oz/gal., pH 1.5	S-253528-18	Moderate Corrosion	D+
		-19	Severe Corrosion	
		-20	Severe Corrosion	
	1.25 oz/gal., pH 0.9	S-253528-35	Moderate Corrosion	C
		-36	Moderate Corrosion	
		-37	Moderate Corrosion	
	6 oz/gal., pH 0.7	S-253528-52	Moderate Corrosion	C-
		-53	Moderate Corrosion	
		-54	Moderate Corrosion	
6061-T6	1.25 oz/gal., pH 1.5	S-283387-1	No Corrosion	A
		-2	No Corrosion	
		-3	No Corrosion	
	Scotch Brite + 1.25 oz/gal., pH 1.5	S-283387-18	No Corrosion	A
		-19	No Corrosion	
		-20	No Corrosion	
	1.25 oz/gal., pH 0.9	S-283387-35	No Corrosion	A
		-36	No Corrosion	
		-37	No Corrosion	
	6 oz/gal., pH 0.7	S-283387-52	No Corrosion	A
		-53	No Corrosion	
		-54	No Corrosion	

TABLE 42
EXPOSURE SAMPLES OF S-290082, 0.50" 2219-F ALLOY

Treatment	Coating Weight	Salt Spray	Humidity	New Ken	Pt. Judith	Miami
Mill Finish; Clean; H_2SO_4-CrO_3 1.25 oz/gal., pH 1.5, 85°F, 3 min.	82 mg/sqft	-1,-2	-3,-4	-5,-6	-7,-8	-9,-10
Mill Finish; Clean; H_2SO_4-CrO_3 1.25 oz/gal., pH 0.9, 85°F, 3 min.	148 mg/sqft	-12,-13	-14,-15	-16,-17	-18,-19	-20,-21
Mill Finish; Clean; H_2SO_4-CrO_3 6 oz/gal., pH 0.7, 70°F, 3 min.	248 mg/sqft	-23,-24	-25,-26	-27,-28	-29,-30	-31,-32

TABLE 43
SALT SPRAY EVALUATION TEST NO. 3 - VARIOUS TEMPERS OF 2219 ALLOY

Temper	Gage	Coating	Identification	Results After 168 Hrs. Exp.	Rating
-F	0.50"	1.25 oz/gal., pH 1.5	S-290082-1	Severe Corrosion	D
			-2	Severe Corrosion	
		1.25 oz/gal., pH 0.9	S-290082-12	Moderate Corrosion	C
			-13	Moderate Corrosion	
		6 oz/gal., pH 0.7	S-290082-23	Moderate Corrosion	C
			-24	Moderate Corrosion	
-T37	0.50"	1.25 oz/gal., pH 1.5	S-290081-1	Very Mild Corrosion	B
			-2	Moderate Corrosion	
		1.25 oz/gal., pH 0.9	S-290081-12	No Corrosion	A
			-13	No Corrosion	
		6 oz/gal., pH 0.7	S-290081-23	No Corrosion	A
			-24	No Corrosion	
-T87	0.125"	1.25 oz/gal., pH 0.9	S-298529-1	Moderate Corrosion	C
			-2	Moderate Corrosion	
		1.25 oz/gal., pH 0.9	S-298529-15	Moderate Corrosion	C
		Dichromate - Sealed	-16	Moderate Corrosion	
-T87	0.50"	Machined - Outer Surf.	S-290080-1	No Corrosion	A-
		1.25 oz/gal., pH 1.5	-2	Very Mild Corrosion	
		Machined - Inner Surf.	S-290080-1S	No Corrosion	A-
		1.25 oz/gal., pH 1.5	-2S	Very Mild Corrosion	

TABLE 44
SALT SPRAY EVALUATION CONTINUED TO 336 HOURS - VARIOUS TEMPERS OF 2219 ALLOY

Temper	Gage	Coating	Identification	Results After 336 Hrs. Exp.	Rating
-F	0.50"	1.25 oz/gal., pH 1.5	S-290082-1 -2	Severe Corrosion Severe Corrosion	D-
		1.25 oz/gal., pH 0.9	S-290082-12 -13	Severe Corrosion Severe Corrosion	D
		6 oz/gal., pH 0.7	S-290082-23 -24	Severe Corrosion Severe Corrosion	D-
-T37	0.50"	1.25 oz/gal., pH 1.5	S-290081-1 -2	Severe Corrosion Severe Corrosion	D+
		1.25 oz/gal., pH 0.9	S-290081-12 -13	Severe Corrosion Severe Corrosion	D
		6 oz/gal., pH 0.7	S-290081-23 -24	Mild Corrosion Mild Corrosion	B
-T87	0.125"	1.25 oz/gal., pH 0.9	S-298529-1 -2	Severe Corrosion Severe Corrosion	D+
		1.25 oz/gal., pH 0.9 Dichromate Sealed	S-209529-15 -16	Moderate Corrosion Moderate Corrosion	C-
-T87	0.50"	Machined-Outer Surface 1.25 oz/gal., pH 1.5	S-290080-1 -2	Severe Corrosion Severe Corrosion	D+
		Machined-Inner Surface 1.25 oz/gal., pH 1.5	S-290080-1S -2S	Severe Corrosion Severe Corrosion	D+

TABLE 45
EXPOSURE SAMPLES OF S-298551, 0.50" 2219-T62 ALLOY

Treatment	Coating Weight	Salt Spray	Humidity	New Ken	Pt. Judith	Miami
Mill Finish; Clean; H_2SO_4-CrO_3 1.25 oz/gal,, pH 1.5, 85°F, 3 min.	33 mg/sqft	-1,-2	-3,-4	-5,-6	-7,-8	-9,-10
Mill Finish; Clean; H_2SO_4-CrO_3 1.25 oz/gal., pH 0.9, 85°F, 3 min.	58 mg/sqft	-12,-13	-14,-15	-16,-17	-18,-19	-20,-21
Mill Finish; Clean; H_2SO_4-CrO_3 6 oz/gal., pH 0.7, 70°F, 3 min.	73 mg/sqft	-23,-24	-25,-26	-27,-28	-29,-30	-31,-32

TABLE 46
SALT SPRAY EVALUATION TEST NO. 5 - S-298551, 0.50", 2219-T62 ALLOY

Treatment	Identification	Results After 168 Hrs. Exp.	Rating
1.25 oz/gal., pH 1.5, 85°F, 3 min.	S-298551-1	Very Mild Corrosion	A-
	-2	Very Mild Corrosion	
1.25 oz/gal., pH 0.9, 85°F, 3 min.	S-298551-12	Very Mild Corrosion	A-
	-13	Very Mild Corrosion	
6 oz/gal., pH 0.7, 70°F, 3 min.	S-298551-23	No Corrosion	A
	-24	No Corrosion	

TABLE 47
SALT SPRAY EVALUATION CONTINUED TO 336 HOURS - S-298551, 0.50", 2219-T62 ALLOY

Treatment	Identification	Results After 336 Hrs. Exp.	Rating
1.25 oz/gal., pH 1.5, 85°F, 3 min.	S-298551-1 -2	Severe Corrosion Severe Corrosion	D-
1.25 oz/gal., pH 0.9, 85°F, 3 min.	S-298551-12 -13	Severe Corrosion Severe Corrosion	D
6 oz/gal., pH 0.7, 70°F, 3 min.	S-298551-23 -24	Moderate Corrosion Severe Corrosion	C-

TABLE 48
EXPOSURE SAMPLES OF S-290081, 0.50" 2219-T37 ALLOY

Treatment	Coating Weight	Salt Spray	Humidity	New Ken	Pt. Judith	Miami
Mill Finish; Clean; H_2SO_4-CrO_3 1.25 oz/gal., pH 1.5, 85°F, 3 min.	40 mg/sqft	-1,-2	-3,-4	-5,-6	-7,-8	-9,-10
Mill Finish; Clean; H_2SO_4-CrO_3 1.25 oz/gal., pH 0.9, 85°F, 3 min.	76 mg/sqft	-12,-13	-14,-15	-16,-17	-18,-19	-20,-21
Mill Finish; Clean; H_2SO_4-CrO_3 6 oz/gal., pH 0.7, 70°F, 3 min.	78 mg/sqft	-23,-24	-25,-26	-27,-28	-29,-30	-31,-32

TABLE 49
EXPOSURE SAMPLES OF S-290080, 0.50" 2219-T87 ALLOY

Treatment	Coating Weight	Salt Spray	Humidity	New Ken	Pt. Judith	Miami
Machined, Outer Surface, Clean. 1.25 oz/gal., pH 1.5, 85°F, 3 min.	148 mg/sqft	-1,-2	-3,-4	-5,-6	-7,-8	-9,-10
Machined, Inner Surface, Clean. 1.25 oz/gal., pH 1.5, 85°F, 3 min.	92 mg/sqft	-1S,-2S	-3S,-4S	-5S,-6S	-7S,-8S	-9S,-10S

TABLE 50
EXPOSURE SAMPLES OF S-298548, 0.50" 2219-T87 ALLOY

Treatment	Coating Weight	Salt Spray	Humidity	New Ken	Pt. Judith	Miami
Mill Finish; Clean; H_2SO_4-CrO_3 1.25 oz/gal., pH 1.5, 85°F, 3 min.	40 mg/sqft	B-1,-2	B-3,-4	B-5,-6	B-7,-8	B-9,-10
Mill Finish; Clean; H_2SO_4-CrO_3 1.25 oz/gal., pH 0.9, 85°F, 3 min.	97 mg/sqft	B-12,-13	B-14,-15	B-16,-17	B-18,-19	B-20,-21
Mill Finish; Clean; H_2SO_4-CrO_3 6 oz/gal., pH 0.7, 70°F, 3 min.	76 mg/sqft	B-23,-24	B-25,-26	B-27,-28	B-29,-30	B-31,-32
Machined; Clean. 1.25 oz/gal., pH 1.5, 85°F, 3 min.	68 mg/sqft	C-1,-2	C-3,-4	C-5,-6	C-7,-8	C-9,-10
Chem Milled; Clean. 1.25 oz/gal., pH 1.5, 85°F, 3 min.	62 mg/sqft	A-1,-2	A-3,-4	A-5,-6	A-7,-8	A-9,-10
Chem Milled; Clean. 1.25 oz/gal., pH 0.9,85°F, 3 min.	84 mg/sqft	A-12,-13	A-14,-15	A-16,-17	A-18,-19	A-20,-21
Chem Milled; Clean. 6 oz/gal., pH 0.7, 70°F, 3 min.	71 mg/sqft	A-23,-24	A-25,-26	A-27,-28	A-29,-30	A-31,-32

TABLE 51
SALT SPRAY EVALUATION TEST NO. 4 - S-298548, 0.50", 2219-T87 ALLOY

Surface	Coating	Identification	Results After 168 Hrs. Exp.	Rating
Mill Finish; Clean; H_2SO_4-CrO_3	1.25 oz/gal., pH 1.5	S-298548 B-1 B-2	Moderate Corrosion Moderate Corrosion	C
Mill Finish; Clean; H_2SO_4-CrO_3	1.25 oz/gal., pH 0.9	S-298548 B-12 B-13	Moderate Corrosion Moderate Corrosion	C+
Mill Finish; Clean; H_2SO_4-CrO_3	6 oz/gal., pH 0.7	S-298548 B-23 B-24	Moderate Corrosion Mild Corrosion	B-
Machined; Clean.	1.25 oz/gal., pH 1.5	S-298548 C-1 C-2	No Corrosion No Corrosion	A
Chem Milled; Clean.	1.25 oz/gal., pH 1.5	S-298548 A-1 A-2	Moderate Corrosion Moderate Corrosion	C
Chem Milled; Clean.	1.25 oz/gal., pH 0.9	S-298548 A-12 A-13	Mild Corrosion Moderate Corrosion	B-
Chem Milled; Clean.	6 oz/gal., pH 0.7	S-298548 A-23 A-24	Moderate Corrosion Moderate Corrosion	C+

TABLE 52
SALT SPRAY EVALUATION CONTINUED TO 336 HOURS - S-298548, 0.50", 2219-T87 ALLOY

Surface	Coating	Identification	Results After 336 Hrs. Exp.	Rating
Mill Finish; Clean; H_2SO_4-CrO_3	1.25 oz/gal., pH 1.5	S-298548-B1 -B2	Severe Corrosion Severe Corrosion	D-
Mill Finish; Clean; H_2SO_4-CrO_3	1.25 oz/gal., pH 0.9	S-298548-B12 -B13	Moderate Corrosion Moderate Corrosion	C-
Mill Finish; Clean; H_2SO_4-CrO_3	6 oz/gal., pH 0.7	S-298548-B23 -B24	Severe Corrosion Severe Corrosion	D
Machined; Clean	1.25 oz/gal., pH 1.5	S-298548-C1 -C2	Moderate Corrosion Moderate Corrosion	C-
Chem Milled; Clean	1.25 oz/gal., pH 1.5	S-298548-A1 -A2	Severe Corrosion Severe Corrosion	D
Chem Milled; Clean	1.25 oz/gal., pH 0.9	S-298548-A12 -A13	Severe Corrosion Severe Corrosion	D+
Chem Milled; Clean	6 oz/gal., pH 0.7	S-298548-A23 -A24	Severe Corrosion Severe Corrosion	D

TABLE 53
EXPOSURE SAMPLES OF S-298529, 0.125" 2219-T87 ALLOY

Treatment	Coat. Wt.	Salt Spray	Humidity	New Ken	Pt. Judith	Miami
Mill Finish; Clean; H_2SO_4-CrO_3 1.25 oz/gal., pH 0.9, 85°F, 3 min.	61 mg/sqft	-1,-2	-3,-4	-5,-6,-7	-8,-9,-10	-11,-12,-13
Mill Finish; Clean; H_2SO_4-CrO_3 1.25 oz/gal., pH 0.9, 85°F, 3 min. Dichromate Seal; 140°F, 3 min.	61 mg/sqft	-15,-16	-17,-18	-19,-20,-21	-22,-23,-24	-25,-26,-27

TABLE 54
EXPOSURE SAMPLES OF S-298552, 0.125" 2219-T87 ALLOY

Treatment	Coat. Wt.	Salt Spray	Humidity	New Ken	Pt. Judith	Miami
Mill Finish; Clean; H_2SO_4-CrO_3 1.25 oz/gal., pH 1.5, 85°F, 3 min.	23 mg/sqft	A-1,-2	A-3,-4	A-5,-6,-7	A-8,-9,-10	A-11,-12,-13
Mill Finish; Clean; H_2SO_4-CrO_3 1.25 oz/gal., pH 0.9, 85°F, 3 min.	56 mg/sqft	A-16,-17	A-18,-19	A-20,-21,-22	A-23,-24,-25	A-26,-27,-28
Mill Finish; Clean; H_2SO_4-CrO_3 6 oz/gal., pH 0.7, 70°F, 3 min.	58 mg/sqft	A-31,-32	A-33,-34	A-35,-36,-37	A-38,-39,-40	A-41,-42,-43
Mill Finish; Clean; HNO_3-HF 1.25 oz/gal., pH 1.5, 85°F, 3 min.	33 mg/sqft	B-1,-2	B-3,-4	B-5,-6,-7	B-8,-9,-10	B-11,-12,-13
Mill Finish; Clean; HNO_3-HF 1.25 oz/gal., pH 0.9, 85°F, 3 min.	46 mg/sqft	B-16,-17	B-18,-19	B-20,-21,-22	B-23,-24,-25	B-26,-27,-28
Mill Finish; Clean; HNO_3-HF 6 oz/gal., pH 0.9, 70°F, 3 min.	62 mg/sqft	B-31,-32	B-33,-34	B-35,-36,-37	B-38,-39,-40	B-41,-42,-43
Mill Finish; Clean; H_2SO_4-HNO_3 1.25 oz/gal., pH 1.5, 85°F, 3 min.	25 mg/sqft	C-1,-2	C-3,-4	C-5,-6,-7	C-8,-9,-10	C-11,-12,-13
Mill Finish; Clean; H_2SO_4-HNO_3 1.25 oz/gal., pH 0.9, 85°F, 3 min.	52 mg/sqft	C-16,-17	C-18,-19	C-20,-21,-22	C-23,-24,-25	C-26,-27,-28
Mill Finish; Clean; H_2SO_4-HNO_3 6 oz/gal., pH 0.7, 70°F, 3 min.	76 mg/sqft	C-31,-32	C-33,-34	C-35,-36,-37	C-38,-39,-40	C-41,-42,-43

TABLE 54
EXPOSURE SAMPLES OF S-298552, 0.125" 2219-T87 ALLOY
(Continued)

Treatment	Coat. Wt.	Salt Spray	Humidity	New Ken	Pt. Judith	Miami
Scotch Brite; Clean. 1.25 oz/gal., pH 1.5, 85°F, 3 min.	49 mg/sqft	D-1,-2	D-3,-4	D-5,-6,-7	D-8,-9,-10	D-11,-12,-13
Scotch Brite; Clean. 1.25 oz/gal., pH 0.9, 85°F, 3 min.	91 mg/sqft	D-16,-17	D-18,-19	D-20,-21,-22	D-23,-24,-25	D-26,-27,-28
Scotch Brite; Clean. 6 oz/gal., pH 0.7, 70°F, 3 min.	176 mg/sqft	D-31,-32	D-33,-34	D-35,-36,-37	D-38,-39,-40	D-41,-42,-43

TABLE 55

SALT SPRAY EVALUATION TEST NO. 6 - S-298552, 0.125" 2219-T87 ALLOY

Deoxidizer	Coating	Identification	Results After 168 Hrs. Exp.	Rating
H_2SO_4-CrO_3	1.25 oz/gal., pH 1.5	S-298552 A-1 A-2	Severe Corrosion Severe Corrosion	D
H_2SO_4-CrO_3	1.25 oz/gal., pH 0.9	S-298552 A-16 A-17	Moderate Corrosion Moderate Corrosion	C
H_2SO_4-CrO_3	6 oz/gal., pH 0.7	S-298552 A-31 A-32	Moderate Corrosion Mild Corrosion	C+
HNO_3-HF	1.25 oz/gal., pH1.5	S-298552 B-1 B-2	Moderate Corrosion Moderate Corrosion	C
HNO_3-HF	1.25 oz/gal., pH 0.9	S-298552 B-16 B-17	Moderate Corrosion Moderate Corrosion	C
HNO_3-HF	6 oz/gal., pH 0.7	S-298552 B-31 B-32	Moderate Corrosion Mild Corrosion	C+
H_2SO_4-HNO_3	1.25 oz/gal., pH 1.5	S-298552 C-1 C-2	Moderate Corrosion Moderate Corrosion	C-
H_2SO_4-HNO_3	1.25 oz/gal., pH 0.9	S-298552 C-16 C-17	Mild Corrosion Moderate Corrosion	C+
H_2SO_4-HNO_3	6 oz/gal., pH 0.7	S-298552 C-31 C-32	Mild Corrosion Mild Corrosion	B
Scotch Brite	1.25 oz/gal., pH 1.5	S-298552 D-1 D-2	Mild Corrosion Moderate Corrosion	B-
Scotch Brite	1.25 oz/gal., pH 0.9	S-298552 D-16 D-17	Mild Corrosion No Corrosion	B+
Scotch Brite	6 oz/gal., pH 0.7	S-298552 D-31 D-32	Very Mild Corrosion Very Mild Corrosion	A-

TABLE 56

SALT SPRAY EVALUATION CONTINUED TO 336 HOURS - S-298552, 0.125" 2219-T87 ALLOY

Deoxidizer	Coating	Identification	Results After 336 Hrs. Exp.	Rating
H_2SO_4-CrO_3	1.25 oz/gal., pH 1.5	S-298552-A1 -A2	Severe Corrosion Severe Corrosion	D-
H_2SO_4-CrO_3	1.25 oz/gal., pH 0.9	S-298552-A16 -A17	Severe Corrosion Severe Corrosion	D-
H_2SO_4-CrO_3	6 oz/gal., pH 0.7	S-298552-A31 -A32	Severe Corrosion Severe Corrosion	D-
HNO_3-HF	1.25 oz/gal., pH 1.5	S-298552-B1 -B2	Severe Corrosion Severe Corrosion	D-
HNO_3-HF	1.25 oz/gal., pH 0.9	S-298552-B16 -B17	Severe Corrosion Severe Corrosion	D-
HNO_3-HF	6 oz/gal., pH 0.7	S-298552-B31 -B32	Severe Corrosion Severe Corrosion	D-
H_2SO_4-HNO_3	1.25 oz/gal., pH 1.5	S-298552-C1 -C2	Severe Corrosion Severe Corrosion	D-
H_2SO_4-HNO_3	1.25 oz/gal., pH 0.9	S-298552-C16 -C17	Severe Corrosion Severe Corrosion	D
H_2SO_4-HNO_3	6 oz/gal., pH 0.7	S-298552-C31 -C32	Severe Corrosion Severe Corrosion	D
Scotch Brite	1.25 oz/gal., pH 1.5	S-298552-D1 -D2	Severe Corrosion Severe Corrosion	D
Scotch Brite	1.25 oz/gal., pH 0.9	S-298552-D16 -D17	Moderate Corrosion Moderate Corrosion	C
Scotch Brite	6 oz/gal., pH 0.7	S-298552-D31 -D32	Moderate Corrosion Moderate Corrosion	C+

TABLE 57
THREE MONTHS HUMIDITY EXPOSURE - 2014, 5052, 6061, 7075 ALLOYS

Alloy	Coating	Identification	Results After 3 Months Exposure*
2014-T6	1.25 oz/gal., pH 1.5, 3 min.	S-253528-4,5,6	No Corrosion or Staining
	Scotch Brite + Above	-21,22,23	No Corrosion or Staining
	1.25 oz/gal., pH 0.9, 1 min.	-38,39,40	No Corrosion or Staining
	6 oz/gal., pH 0.7, 1 min.	-55,56,57	No Corrosion or Staining
5052-H38	1.25 oz/gal., pH 1.5, 3 min.	S-65644-4,5,6	No Corrosion or Staining
	Scotch Brite + Above	-21,22,23	No Corrosion or Staining
	1.25 oz/gal., pH 0.9, 1 min.	-38,39,40	No Corrosion or Staining
	6 oz/gal., pH 0.7, 1 min.	-55,56,57	Small Area of Staining on Back
6061-T6	1.25 oz/gal., pH 1.5, 3 min.	S-283387-4,5,6	No Corrosion or Staining
	Scotch Brite + Above	-21,22,23	No Corrosion or Staining
	1.25 oz/gal., pH 0.9, 1 min.	-38,39,40	No Corrosion or Staining
	6 oz/gal., pH 0.7, 1 min.	-55,56,57	No Corrosion or Staining
7075-T6	1.25 oz/gal., pH 1.5, 3 min.	S-252880-4,5,6	No Corrosion or Staining
	Scotch Brite + Above	-21,22,23	No Corrosion or Staining
	1.25 oz/gal., pH 0.9, 1 min.	-38,39,40	No Corrosion or Staining
	6 oz/gal., pH 0.7, 1 min.	-55,56,57	No Corrosion or Staining

* 100% R.H. at 125^{O}F

TABLE 58
THREE MONTHS HUMIDITY EXPOSURE - VARIOUS TEMPERS OF 2219 ALLOY

Temper	Gage	Coating	Identification	Results After 3 Months Exposure*
-F	0.50"	1.25 oz/gal., pH 1.5	S-290082-3,4	Small Stained Areas-Front and Back
		1.25 oz/gal., pH 0.9	-14,15	Staining-Front and Back
		6 oz/gal., pH 0.7	-25,26	No Corrosion or Staining
-T37	0.50"	1.25 oz/gal., pH 1.5	S-290081-3,4	Stained Area, Bottom Half, Front and Back
		1.25 oz/gal., pH 0.9	-14,15	Small Stained Area Around Hole, Front
		6 oz/gal., pH 0.7	-25,26	No Corrosion or Staining
-T62	0.50"	1.25 oz/gal., pH 1.5	S-298551-3,4	Dark Stain on Bottom Edge
		1.25 oz/gal., pH 0.9	-14,15	Small Stained Area-#14, Front
		6 oz/gal., pH 0.7	-25,26	Small Stained Area-#26, Back
-T87	0.125"	1.25 oz/gal., pH 0.9	S-298529-3,4	No Corrosion or Staining
		Above Sealed in Dichromate	-17,18	No Corrosion or Staining
-T87	0.50"	Outer Surf.-1.25 oz/gal., pH 1.5	S-290080-3,4	No Corrosion or Staining
		Inner Surf.-1.25 oz/gal., pH 1.5	-3S,4S	No Corrosion or Staining

* 100% R. H. at 95°F

TABLE 59
THREE MONTHS HUMIDITY EXPOSURE - S-298548, 0.50" 2219-T87 ALLOY

Surface	Coating	Identification	Results After 3 Months Exposure*
Mill Finish; Clean; H_2SO_4-CrO_3	1.25 oz/gal., pH 1.5	S-298548-B3,B4	Back stained; small stain on front
	1.25 oz/gal., pH 0.9	-B14,B15	Small stain on front of B14
	6 oz/gal., pH 0.7	-B25,B26	Small stain on back of B25
Machined; Clean	1.25 oz/gal., pH 1.5	S-298548-C3,C4	Dark stain on back
Chem Milled; Clean	1.25 oz/gal., pH 1.5	S-298548-A3,A4	Staining on back
	1.25 oz/gal., pH 0.9	-A14,A15	Staining on back
	6 oz/gal., pH 0.7	-A25,A26	Staining on back

* 100% R. H. at 125°F

TABLE 60
THREE MONTHS HUMIDITY EXPOSURE - S-298552, 0.125" 2219-T87 ALLOY

Deoxidizer	Coating	Identification	Results After 3 Months Exposure*
H_2SO_4-CrO_3	1.25 oz/gal., pH 1.5	S-298552-A3,A4	Small Stain on Front
	1.25 oz/gal., pH 0.9	-A18,A19	No Corrosion or Staining
	6 oz/gal., pH 0.7	-A33,A34	No Corrosion or Staining
HNO_3-HF	1.25 oz/gal., pH 1.5	-B3,B4	No Corrosion or Staining
	1.25 oz/gal., pH 0.9	-B18,B19	No Corrosion or Staining
	6 oz/gal., pH 0.7	-B33,B34	No Corrosion or Staining
H_2SO_4-HNO_3	1.25 oz/gal., pH 1.5	-C3,C4	No Corrosion or Staining
	1.25 oz/gal., pH 0.9	-C18,C19	No Corrosion or Staining
	6 oz/gal., pH 0.7	-C33,C34	Small Stain on Back
Scotch Brite	1.25 oz/gal., pH 1.5	-D3,D4	No Corrosion or Staining
	1.25 oz/gal., pH 0.9	-D18,D19	No Corrosion or Staining
	6 oz/gal., pH 0.7	-D33,D34	Large Stain on Back

*100% R. H. at 125°F

TABLE 61

ONE YEAR HUMIDITY EXPOSURE - 2014, 5052, 6061, 7075 ALLOYS

Alloy	Coating	Identification	Results After 1 Year Exposure*
2014-T6	1.25 oz/gal., pH 1.5, 3 min.	S-253528-4,5,6	Stained areas; scattered mild pitting
	Scotch Brite + above	-21,22,23	Small stained areas; very mild scattered pitting
	1.25 oz/gal., pH 0.9, 1 min.	-38,39,40	Small stained areas; very mild scattered pitting
	6 oz/gal., pH 0.7, 1 min.	-55,56,57	Large stained areas; very mild scattered pitting
5052-H38	1.25 oz/gal., pH 1.5, 3 min.	S-65644-4,5,6	No corrosion or staining
	Scotch Brite + above	-21,22,23	Small stained areas
	1.25 oz/gal., pH 0.9, 1 min	-38,39,40	No corrosion or staining
	6 oz/gal., pH 0.7, 1 min.	-55,56,57	Large stained areas
6061-T6	1.25 oz/gal., pH 1.5, 3 min.	S-283387-4,5,6	No corrosion or staining
	Scotch Brite + above	-21,22,23	Small stained areas
	1.25 oz/gal., pH 0.9, 1 min.	-38,39,40	No corrosion or staining
	6 oz/gal., pH 0.7, 1 min.	-55,56,57	Large stained areas
7075-T6	1.25 oz/gal., pH 1.5, 3 min.	S-252880-4,5,6	Very mild scattered pitting; stain on #6
	Scotch Brite + above	-21,22,23	No corrosion or staining
	1.25 oz/gal., pH 0.9, 1 min.	-38,39,40	Very mild scattered pitting
	6 oz/gal., pH 0.7, 1 min.	-55,56,57	Large stained areas; mild scattered pitting

* 100% R. H. at 125°F

TABLE 62

ONE YEAR HUMIDITY EXPOSURE - VARIOUS TEMPERS OF 2219 ALLOY

Temper	Gage	Coating	Identification	Results After 1 Year Exposure
-F	0.50"	1.25 oz/gal., pH 1.5	S-290082-3,4	Large stained areas; moderate uniform pitting
		1.25 oz/gal., pH 0.9	-14,15	Large stained areas; mild uniform pitting
		6 oz/gal., pH 0.7	-25,26	Large stained areas; mild uniform pitting
-T37	0.50"	1.25 oz/gal., pH 1.5	S-290081-3,4	Large stained areas; moderate uniform pitting
		1.25 oz/gal., pH 0.9	-14,15	Large stained areas; mild uniform pitting
		6 oz/gal., pH 0.7	-25,26	Large stained areas; mild uniform pitting
-T62	0.50"	1.25 oz/gal., pH 1.5	S-298551-3,4	Large stained areas; very mild scattered pitting
		1.25 oz/gal., pH 0.9	-14,15	Small stained area
		6 oz/gal., pH 0.7	-25,26	Small stained area; mild scattered pitting
-T87	0.125"	1.25 oz/gal., pH 0.9	S-298529-3,4	Moderate scattered pitting
		Above sealed in dichromate	-17,18	Moderate scattered pitting
-T87	0.50"	Outer surf.-1.25 oz/gal.,pH 1.5	S-290080-3,4	Mild localized pitting
		Inner surf.-1.25 oz/gal.,pH 1.5	-3S,4S	Mild localized pitting

* 100% R. H. at 125°F

TABLE 63

ONE YEAR HUMIDITY EXPOSURE - S-298548, 0.50" 2219-T87 ALLOY

Surface	Coating	Identification	Results After 1 Year Exposure*
Mill Finish; Clean; H_2SO_4-CrO_3	1.25 oz/gal., pH 1.5	S-298548-B3,B4	Large stained areas; moderate to severe pitting
	1.25 oz/gal., pH 0.9	-B14,B15	Large stained areas; moderate scattered pitting
	6 oz/gal., pH 0.7	-B25,B26	Large stained areas; mild to moderate pitting
Machined; Clean	1.25 oz/gal., pH 1.5	S-298548-C3,C4	Small stained areas; few sites mild pitting
Chem Milled; Clean	1.25 oz/gal., pH 1.5	S-298548-A3,A4	Small stained areas; moderate localized pitting
	1.25 oz/gal., pH 0.9	-A14,A15	Mild scattered pitting
	6 oz/gal., pH 0.7	-A25,A26	Small stained areas, moderate localized pitting

* 100% R. H. at 125°F

TABLE 64
ONE YEAR HUMIDITY EXPOSURE - S-298552, 0.125" 2219-T87 ALLOY

Deoxidizer	Coating	Identification	Results After 1 Year Exposure*
H_2SO_4-CrO_3	1.25 oz/gal., pH 1.5	S-298552-A3,A4	Small stained areas; mild uniform pitting
	1.25 oz/gal., pH 0.9	-A18,A19	Mild scattered pitting
	6 oz/gal., pH 0.7	-A33,A34	Mild scattered pitting
HNO_3-HF	1.25 oz/gal., pH 1.5	-B3,B4	Mild scattered pitting
	1.25 oz/gal., pH 0.9	-B18,B19	Mild scattered pitting
	6 oz/gal., pH 0.7	-B33,B34	Mild scattered pitting
H_2SO_4-HNO_3	1.25 oz/gal., pH 1.5	-C3,C4	Mild scattered pitting
	1.25 oz/gal., pH 0.9	-C18,C19	Mild scattered pitting
	6 oz/gal., pH 0.7	-C33,C34	Large stained area; mild scattered pitting
Scotch Brite	1.25 oz/gal., pH 1.5	-D3,D4	Moderate localized pitting
	1.25 oz/gal., pH 0.9	-D18,D19	Mild localized pitting
	6 oz/gal., pH 0.7	-D33,D34	Small stained areas; mild pitting

*** 100% R.H. at 125°F**

TABLE 65
ONE YEAR EXPOSURE TO NEW KENSINGTON, PA. ATMOSPHERE
2014, 5052, 6061, 7075 ALLOYS

Alloy	Coating	Identification	Results After 1 Year Exposure
2014-T6	1.25 oz/gal., pH 1.5, 3 min.	S-253528-7,8,9	Very mild pitting; slight darkening
	Scotch Brite + above	-24,25,26	Very mild pitting; slight darkening
	1.25 oz/gal., pH 0.9, 1 min.	-41,42,43	Very mild pitting; slight darkening
	6 oz/gal., pH 0.7, 1 min.	-58,59,60	Very mild pitting; slight darkening
5052-H38	1.25 oz/gal., pH 1.5, 3 min.	S-65644-7,8,9	No corrosion
	Scotch Brite + above	-24,25,26	No corrosion
	1.25 oz/gal., pH 0.9, 1 min.	-41,42,43	No corrosion
	6 oz/gal., pH 0.7, 1 min.	-58,59,60	No corrosion
6061-T6	1.25 oz/gal., pH 1.5, 3 min.	S-283387-7,8,9	No corrosion
	Scotch Brite + above	-24,25,26	No corrosion
	1.25 oz/gal., pH 0.9, 1 min.	-41,42,43	No corrosion
	6 oz/gal., pH 0.7, 1 min.	-58,59,60	Slight darkening
7075-T6	1.25 oz/gal., pH 1.5, 3 min.	S-252880-7,8,9	Very mild superficial attack
	Scotch Brite + above	-24,25,26	Very mild superficial attack
	1.25 oz/gal., pH 0.9, 1 min.	-41,42,43	No corrosion
	6 oz/gal., pH 0.7, 1 min.	-58,59,60	Very mild superficial attack

TABLE 66
ONE YEAR EXPOSURE TO NEW KENSINGTON, PA. ATMOSPHERE
VARIOUS TEMPERS OF 2219 ALLOY

Temper	Gage	Coating	Identification	Results After 1 Year Exposure
-F	0.50"	1.25 oz/gal., pH 1.5	S-290082-5,6	Mild pitting; spots of white c.p.
		1.25 oz/gal., pH 0.9	-16,17	Mild pitting; spots of white c.p.
		6 oz/gal., pH 0.7	-27,28	Mild pitting; spots of white c.p.
-T37	0.50"	1.25 oz/gal., pH 1.5	S-290081-5,6	No corrosion
		1.25 oz/gal., pH 0.9	-16,17	No corrosion
		6 oz/gal., pH 0.7	-27,28	No corrosion
-T62	0.50"	1.25 oz/gal., pH 1.5	S-298551-5,6	Mild uniform pitting
		1.25 oz/gal., pH 0.9	-16,17	Mild uniform pitting; darkening
		6 oz/gal., pH 0.7	-27,28	Mild uniform pitting; darkening
-T87	0.125"	1.25 oz/gal., pH 0.9	S-298529-5,6,7	Mild uniform pitting
		Above sealed in dichromate	-19,20,21	Mild uniform pitting
-T87	0.50"	Outer surf.-1.25 oz/gal.,pH 1.5	S-290080-5,6	Very mild uniform pitting
		Inner surf.-1.25 oz/gal.,pH 1.5	-5S,6S	Very mild uniform pitting

TABLE 67
ONE YEAR EXPOSURE TO NEW KENSINGTON, PA. ATMOSPHERE
S-298548, 0.50", 2219-T87 ALLOY

Surface	Coating	Identification	Results After 1 Year Exposure
Mill Finish, Clean, H_2SO_4-CrO_3	1.25 oz/gal., pH 1.5	S-298548-B5,B6	Mild Uniform Pitting
	1.25 oz/gal., pH 0.9	-B16,B17	Mild Uniform Pitting
	6 oz/gal., pH 0.7	-B27,B28	Mild Uniform Pitting
Machined, Clean	1.25 oz/gal., pH 1.5	S-298548-C5,C6	Very Mild Superficial Attack
Chem Milled, Clean	1.25 oz/gal., pH 1.5	S-298548-A5,A6	Very Mild Superficial Attack
	1.25 oz/gal., pH 0.9	-A16,A17	Very Mild Superficial Attack
	6 oz/gal., pH 0.7	-A27,A28	Very Mild Superficial Attack

TABLE 68
ONE YEAR EXPOSURE TO NEW KENSINGTON, PA. ATMOSPHERE
S-298552, 0.125", 2219-T87 ALLOY

Deoxidizer	Coating	Identification	Results After 1 Year Exposure
H_2SO_4-CrO_3	1.25 oz/gal., pH 1.5	S-298552-A5,A6,A7	Mild Uniform Pitting
	1.25 oz/gal., pH 0.9	-A20,A21,A22	Mild Uniform Pitting
	6 oz/gal., pH 0.7	-A35,A36,A37	Mild Uniform Pitting
HNO_3-HF	1.25 oz/gal., pH 1.5	-B5,B6,B7	Mild Uniform Pitting
	1.25 oz/gal., pH 0.9	-B20,B21,B22	Mild Uniform Pitting
	6 oz/gal., pH 0.7	-B35,B36,B37	Mild Uniform Pitting
H_2SO_4-HNO_3	1.25 oz/gal., pH 1.5	-C5,C6,C7	Mild to Moderate Pitting
	1.25 oz/gal., pH 0.9	-C20,C21,C22	Mild to Moderate Pitting
	6 oz/gal., pH 0.7	-C35,C36,C37	Mild to Moderate Pitting
Scotch Brite	1.25 oz/gal., pH 1.5	-D5,D6,D7	Very Mild Uniform Pitting
	1.25 oz/gal., pH 0.9	-D20,D21,D22	Very Mild Uniform Pitting
	6 oz/gal., pH 0.7	-D35,D36,D37	Very Mild Uniform Pitting

TABLE 69
ONE YEAR EXPOSURE TO POINT JUDITH, R.I. ATMOSPHERE
2014, 5052, 6061, 7075 ALLOYS

Alloy	Coating	Identification	Results After 1 Year Exposure
2014-T6	1.25 oz/gal., pH 1.5, 3 min.	S-253528-10,11,12	Mild uniform pitting
	Scotch Brite + above	-27,28,29	Very mild uniform pitting
	1.25 oz/gal., pH 0.9, 1 min.	-44,45,46	Mild uniform pitting
	6 oz/gal., pH 0.7, 1 min.	-61,62,63	Mild uniform pitting
5052-H38	1.25 oz/gal., pH 1.5, 3 min.	S-65644-10,11,12	Very mild uniform pitting
	Scotch Brite + above	-27,28,29	Very mild uniform pitting
	1.25 oz/gal., pH 0.9, 1 min.	-44,45,46	Very mild uniform pitting
	6 oz/gal., pH 0.7, 1 min.	-61,62,63	Very mild uniform pitting
6061-T6	1.25 oz/gal., pH 1.5, 3 min.	S-283387-10,11,12	Moderate uniform pitting
	Scotch Brite + above	-27,28,29	Mild uniform pitting
	1.25 oz/gal., pH 0.9, 1 min.	-44,45,46	Moderate uniform pitting
	6 oz/gal., pH 0.7, 1 min.	-61,62,63	Moderate uniform pitting
7075-T6	1.25 oz/gal., pH 1.5, 3 min.	S-252880-10,11,12	Mild uniform pitting
	Scotch Brite + above	-27,28,29	Moderate uniform pitting
	1.25 oz/gal., pH 0.9, 1 min.	-44,45,46	Mild uniform pitting
	6 oz/gal., pH 0.7, 1 min.	-61,62,63	Mild uniform pitting

TABLE 70
ONE YEAR EXPOSURE TO POINT JUDITH, R.I. ATMOSPHERE
VARIOUS TEMPERS OF 2219 ALLOY

Temper	Gage	Coating	Identification	Results After 1 Year Exposure
-F	0.50"	1.25 oz/gal., pH 1.5	S-290082-7,8	Mild pitting; covered with white c.p.
		1.25 oz/gal., pH 0.9	-18,19	Mild pitting; spots of white c.p.
		6 oz/gal., pH 0.7	-29,30	Mild pitting; spots of white c.p.
-T37	0.50"	1.25 oz/gal., pH 1.5	S-290081-7,8	Mild uniform pitting; slight exfoliation at edges
		1.25 oz/gal., pH 0.9	-18,19	Mild uniform pitting; slight exfoliation at edges
		6 oz/gal., pH 0.7	-29,30	Mild uniform pitting; slight exfoliation at edges
-T62	0.50"	1.25 oz/gal., pH 1.5	S-298551-7,8	Mild uniform attack; covered with white c.p.
		1.25 oz/gal. pH 0.9	-18,19	Mild uniform attack; spots of white c.p
		6 oz/gal., pH 0.7	-29,30	Mild uniform attack; spots of white c.p
-T87	0.125"	1.25 oz/gal., pH 0.9	S-298529-8,9,10	Moderate uniform attack; spots of white c.p.
		Above sealed in dichromate	-22,23,24	Moderate uniform attack; spots of white c.p.
-T87	0.50"	Outer surf.-1.25 oz/gal,pH 1.5	S-290080-7,8	Moderate uniform attack
		Inner surf.-1.25 oz/gal,pH 1.5	-7S,8S	Moderate uniform attack

TABLE 71
ONE YEAR EXPOSURE TO POINT JUDITH, R.I. ATMOSPHERE
S-298548, 0.50", 2219-T87 ALLOY

Surface	Coating	Identification	Results After 1 Year Exposure
Mill Finish, Clean, H_2SO_4-CrO_3	1.25 oz/gal., pH 1.5	S-298548-B7,B8	Moderate uniform attack; covered with white c.p.
	1.25 oz/gal., pH 0.9	-B18,B19	Moderate uniform attack; covered with white c.p.
	6 oz/gal., pH 0.7	-B29,B30	Moderate uniform attack; covered with white c.p.
Machined, Clean	1.25 oz/gal., pH 1.5	S-298548-C7,C8	Mild uniform attack
Chem Milled, Clean	1.25 oz/gal., pH 1.5	S-298548-A7,A8	Moderate uniform attack; spots of white c.p.
	1.25 oz/gal., pH 0.9	-A18,A19	Moderate uniform attack; spots of white c.p.
	6 oz/gal., pH 0.7	-A29,A30	Moderate uniform attack; spots of white c.p.

TABLE 72

ONE YEAR EXPOSURE TO POINT JUDITH, R.I. ATMOSPHERE

S-298552, 0.125", 2219-T87 ALLOY

Deoxidizer	Coating	Identification	Results After 1 Year Exposure
H_2SO_4-CrO_3	1.25 oz/gal., pH 1.5	S-298552-A8,A9,A10	Moderate uniform attack; covered with white c.p.
	1.25 oz/gal., pH 0.9	-A23,A24,A25	Moderate uniform attack; partially covered white c.p.
	6 oz/gal., pH 0.7	-A38,A39,A40	Moderate uniform attack; spots of white c.p.
HNO_3-HF	1.25 oz/gal., pH 1.5	-B8,B9,B10	Moderate uniform attack; spots of white c.p.
	1.25 oz/gal., pH 0.9	-B23,B24,B25	Moderate uniform attack; spots of white c.p.
	6 oz/gal., pH 0.7	-B38,B39,B40	Moderate uniform attack; spots of white c.p.
H_2SO_4- HNO_3	1.25 oz/gal., pH 1.5	-C8,C9,C10	Moderate uniform attack; spots of white c.p.
	1.25 oz/gal., pH 0.9	-C23,C24,C25	Moderate uniform attack; spots of white c.p.
	6 oz/gal., pH 0.7	-C38,C39,C40	Moderate uniform attack; spots of white c.p.
Scotch Brite	1.25 oz/gal., pH 1.5	-D8,D9,D10	Mild uniform attack; spots of white c.p.
	1.25 oz/gal., pH 0.9	-D23,D24,D25	Mild uniform attack; spots of white c.p.
	6 oz/gal., pH 0.7	-D38,D39,D40	Mild uniform attack; spots of white c.p.

TABLE 73
ONE YEAR EXPOSURE TO MIAMI, FLORIDA ATMOSPHERE
2014, 5052, 6061, 7075 ALLOYS

Alloy	Coating	Identification	Results After One Year Exposure
2014-T6	1.25 oz/gal., pH 1.5, 3 Min.	S-253528-13, 14, 15	Very Mild Superficial Attack
	Scotch Brite + Above	-30, 31, 32	Very Mild Superficial Attack
	1.25 oz/gal., pH 0.9, 1 Min.	-47, 48, 49	Very Mild Superficial Attack
	6 oz/gal., pH 0.7, 1 Min.	-64, 65, 66	Very Mild Superficial Attack
5052-H38	1.25 oz/gal., pH 1.5, 3 Min.	S-65644-13, 14, 15	No Corrosion
	Scotch Brite + Above	-30, 31, 32	No Corrosion
	1.25 oz/gal., pH 0.9, 1 Min.	-47, 48, 49	No Corrosion
	6 oz/gal., pH 0.7, 1 Min.	-64, 65, 66	No Corrosion
6061-T6	1.25 oz/gal., pH 1.5, 3 Min.	S-283387-13, 14, 15	No Corrosion
	Scotch Brite + Above	-30, 31, 32	No Corrosion
	1.25 oz/gal., pH 0.9, 1 Min.	-47, 48, 49	No Corrosion
	6 oz/gal., pH 0.7, 1 Min.	-64, 65, 66	Very Mild Scattered Pitting
7075-T6	1.25 oz/gal., pH 1.5, 3 Min.	S-252880-13, 14, 15	Very Mild Superficial Attack
	Scotch Brite + Above	-30, 31, 32	Very Mild Superficial Attack
	1.25 oz/gal., pH 0.9, 1 Min.	-47, 48, 49	Very Mild Superficial Attack
	6 oz/gal., pH 0.7, 1 Min.	-64, 65, 66	Very Mild Superficial Attack

TABLE 74
ONE YEAR EXPOSURE TO MIAMI, FLORIDA ATMOSPHERE
VARIOUS TEMPERS OF 2219 ALLOY

Temper	Gage	Coating	Identification	Results After 1 Year Exposure
-F	0.50"	1.25 oz/gal., pH 1.5	S-290082-9,10	Mild uniform pitting; spots of white c.p
		1.25 oz/gal., pH 0.9	-20,21	Mild uniform pitting; spots of white c.p
		6 oz/gal., pH 0.7	-31,32	Mild uniform pitting; spots of white c.p
-T37	0.50"	1.25 oz/gal., pH 1.5	S-290081-9,10	No corrosion
		1.25 oz/gal., pH 0.9	-20,21	No corrosion
		6 oz/gal., pH 0.7	-31,32	No corrosion
-T62	0.50"	1.25 oz/gal., pH 1.5	S-298551-9,10	Very mild scattered pitting
		1.25 oz/gal., pH 0.9	-20,21	Very mild scattered pitting
		6 oz/gal., pH 0.7	-31,32	Very mild scattered pitting
-T87	0.125"	1.25 oz/gal., pH 0.9	S-298529-11,12,13	Mild scattered pitting
		Above sealed in dichromate	-25,26,27	Mild scattered pitting
-T87	0.50"	Outer surf.-1.25 oz/gal,pH 1.5	S-290080-9,10	Very mild superficial attack
		Inner surf.-1.25 oz/gal,pH 1.5	-9S,10S	Very mild superficial attack

TABLE 75
ONE YEAR EXPOSURE TO MIAMI, FLORIDA ATMOSPHERE
S-298548, 0.50", 2219-T87 ALLOY

Surface	Coating	Identification	Results After 1 Year Exposure
Mill Finish, Clean, H_2SO_4-CrO_3	1.25 oz/gal., pH 1.5	S-298548-B9,B10	Very Mild Superficial Attack
	1.25 oz/gal., pH 0.9	-B20,B21	Very Mild Superficial Attack
	6 oz/gal., pH 0.7	-B31,B32	Very Mild Superficial Attack
Machined, Clean	1.25 oz/gal., pH 1.5	S-298548-C9,C10	Very Mild Scattered Pitting
Chem Milled, Clean	1.25 oz/gal., pH 1.5	S-298548-A9,A10	Very Mild Superficial Attack
	1.25 oz/gal., pH 0.9	-A20,A21	Very Mild Superficial Attack
	6 oz/gal., pH 0.7	-A31,A32	Very Mild Superficial Attack

TABLE 76
ONE YEAR EXPOSURE TO MIAMI, FLORIDA ATMOSPHERE
S-298552, 0.125", 2219-T87 ALLOY

Deoxidizer	Coating	Identification	Results After One Year Exposure
H_2SO_4-CrO_3	1.25 oz/gal., pH 1.5	S-298552-A11, A12, A13	Very Mild Scattered Pitting
	1.25 oz/gal., pH 0.9	-A26, A27, A28	Very Mild Scattered Pitting
	6 oz/gal., pH 0.7	-A41, A42, A43	Mild Scattered Pitting
HNO_3-HF	1.25 oz/gal., pH 1.5	-B11, B12, B13	Very Mild Scattered Pitting
	1.25 oz/gal., pH 0.9	-B26, B27, B28	Mild Scattered Pitting
	6 oz/gal., pH 0.7	-B41, B42, B43	Mild Scattered Pitting
H_2SO_4-HNO_3	1.25 oz/gal., pH 1.5	-C11, C12, C13	Mild Scattered Pitting
	1.25 oz/gal., pH 0.9	-C26, C27, C28	Mild Scattered Pitting
	6 oz/gal., pH 0.7	-C41, C42, C43	Mild Scattered Pitting
Scotch Brite	1.25 oz/gal., pH 1.5	-D11, D12, D13	Very Mild Superficial Attack
	1.25 oz/gal., pH 0.9	-D26, D27, D28	Very Mild Superficial Attack
	6 oz/gal., pH 0.7	-D41, D42, D43	Very Mild Superficial Attack

INDEX OF FIGURES

INDEX OF FIGURES
(Cont.)

INDEX OF FIGURES
(Cont.)

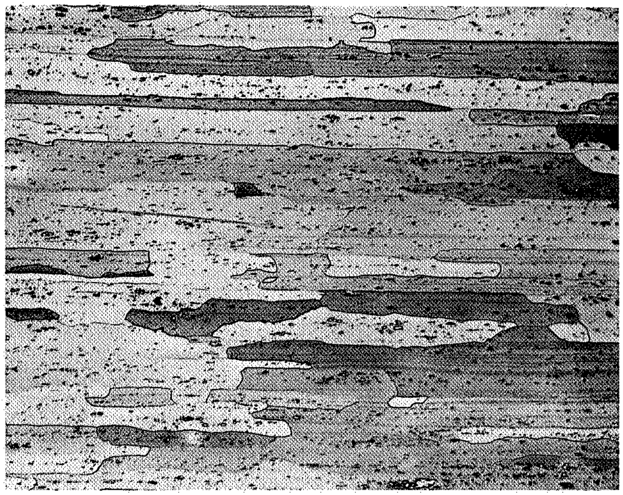


FIG. 1 KELLERS ETCH 100X

STRUCTURE OF 2219-T37 ALLOY

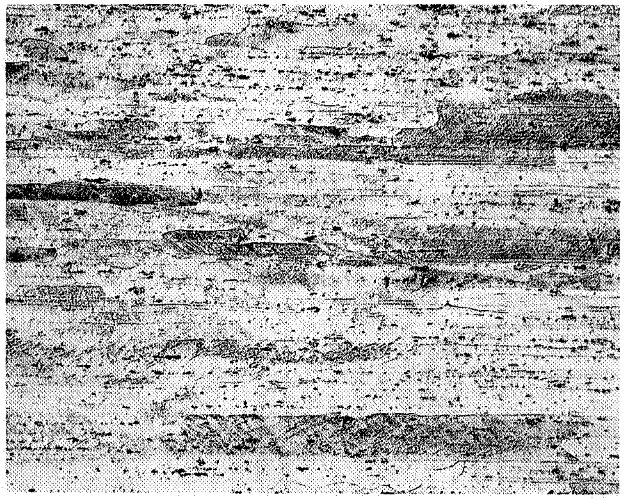


FIG. 2 KELLERS ETCH 100X

STRUCTURE OF 2219-T87 ALLOY

298778J
298779J

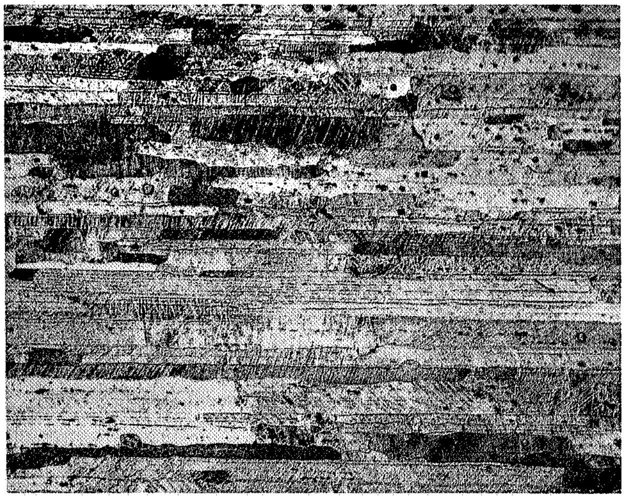


FIG. 3 KELLERS ETCH 100X

STRUCTURE OF 2219-T62 ALLOY

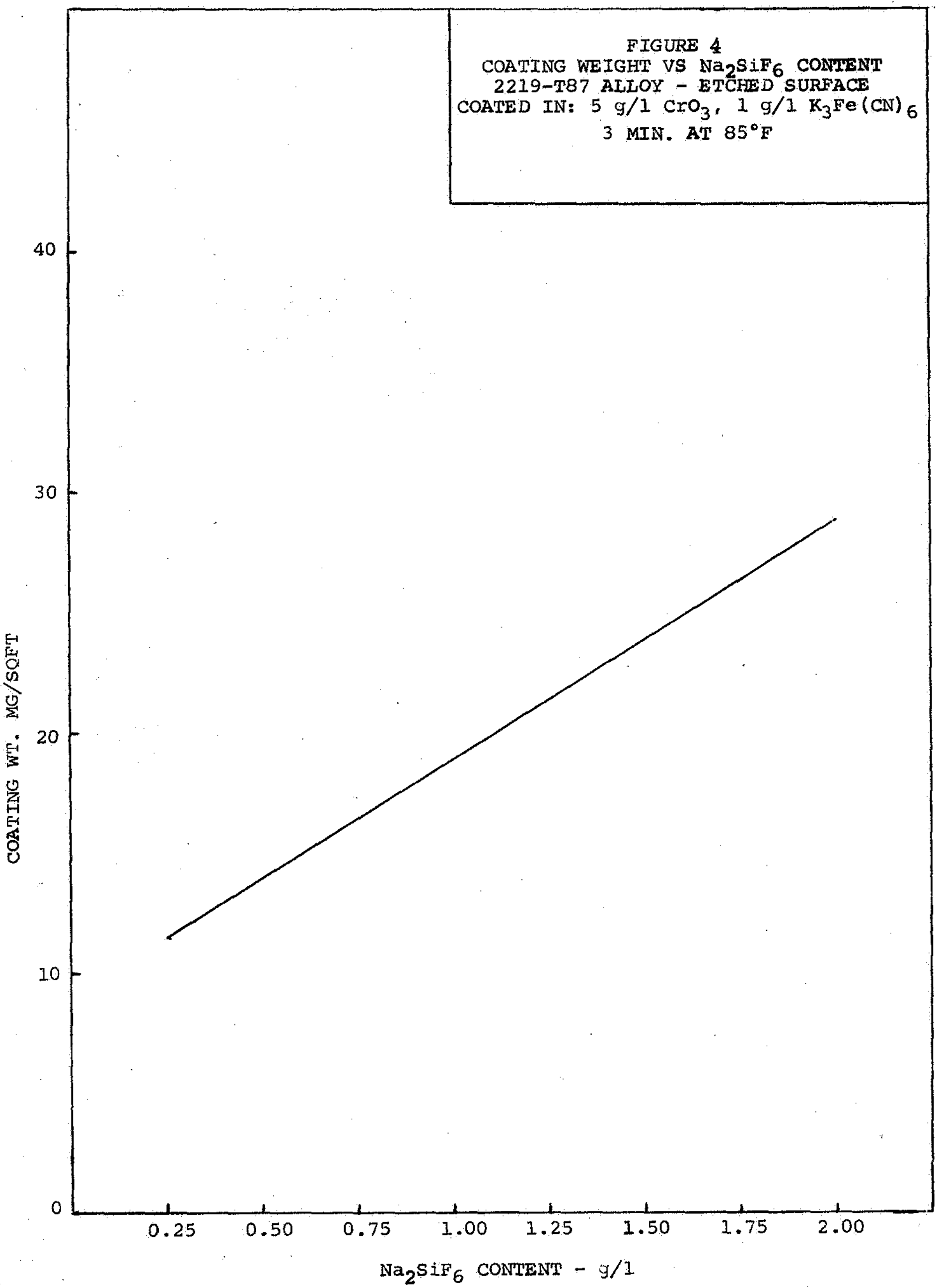


FIGURE 4
COATING WEIGHT VS Na_2SiF_6 CONTENT
2219-T87 ALLOY - ETCHED SURFACE
COATED IN: 5 g/l CrO_3, 1 g/l $K_3Fe(CN)_6$
3 MIN. AT 85°F

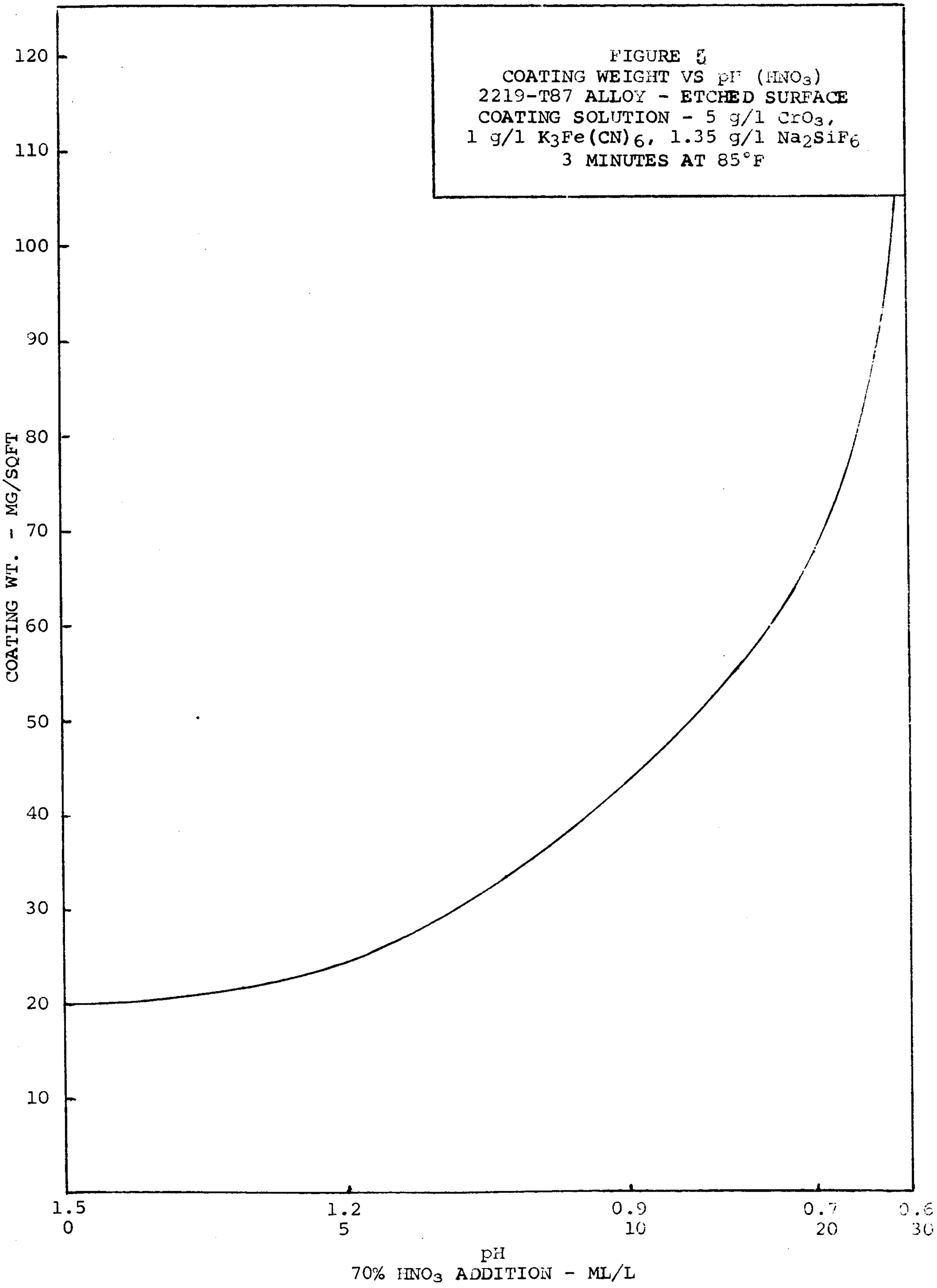


FIGURE 5
COATING WEIGHT VS pH (HNO_3)
2219-T87 ALLOY - ETCHED SURFACE
COATING SOLUTION - 5 g/l CrO_3,
1 g/l $K_3Fe(CN)_6$, 1.35 g/l Na_2SiF_6
3 MINUTES AT 85°F

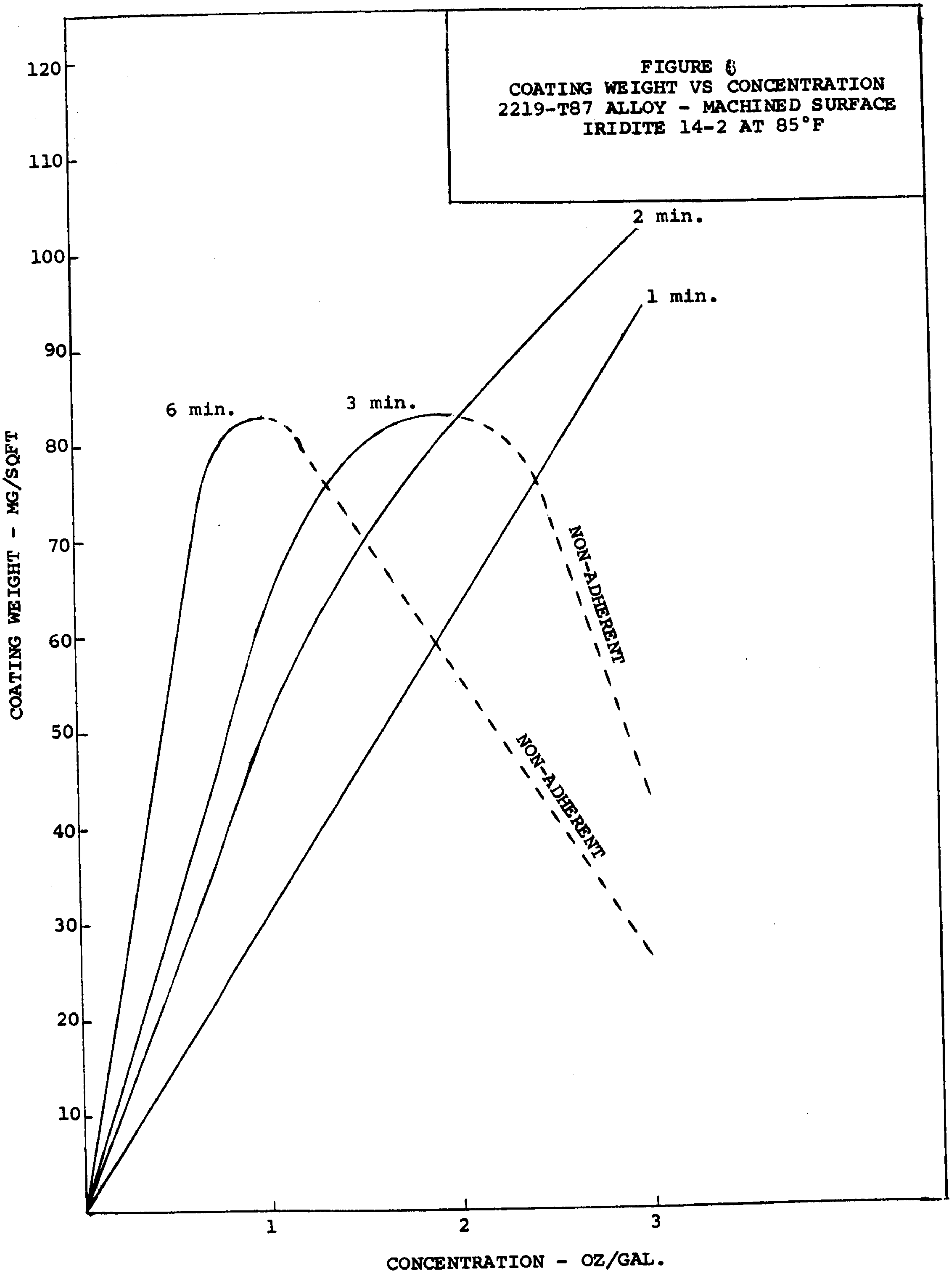


FIGURE 6
COATING WEIGHT VS CONCENTRATION
2219-T87 ALLOY - MACHINED SURFACE
IRIDITE 14-2 AT 85°F

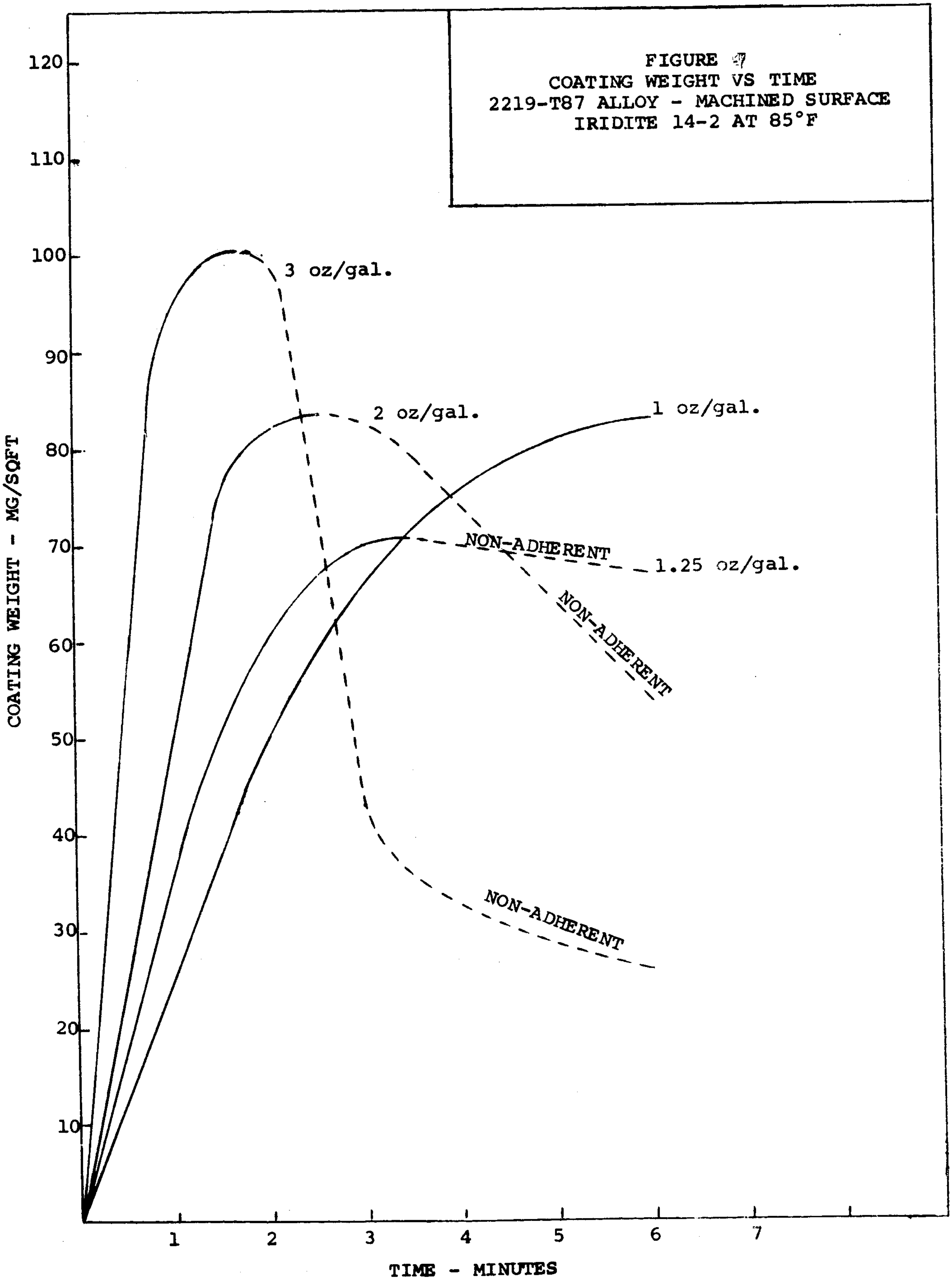


FIGURE 7
COATING WEIGHT VS TIME
2219-T87 ALLOY - MACHINED SURFACE
IRIDITE 14-2 AT 85°F

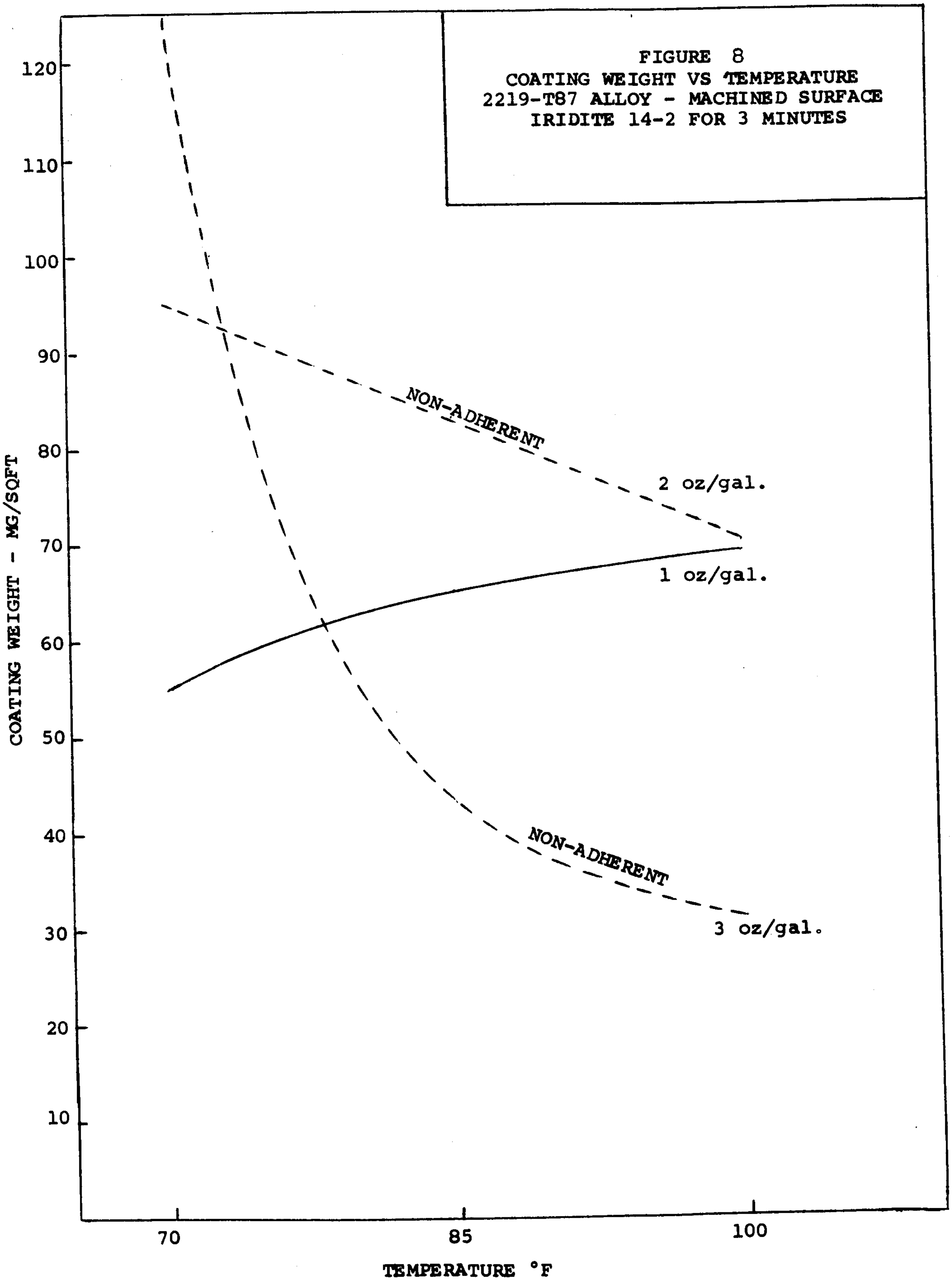


FIGURE 8
COATING WEIGHT VS TEMPERATURE
2219-T87 ALLOY - MACHINED SURFACE
IRIDITE 14-2 FOR 3 MINUTES

60811CJ

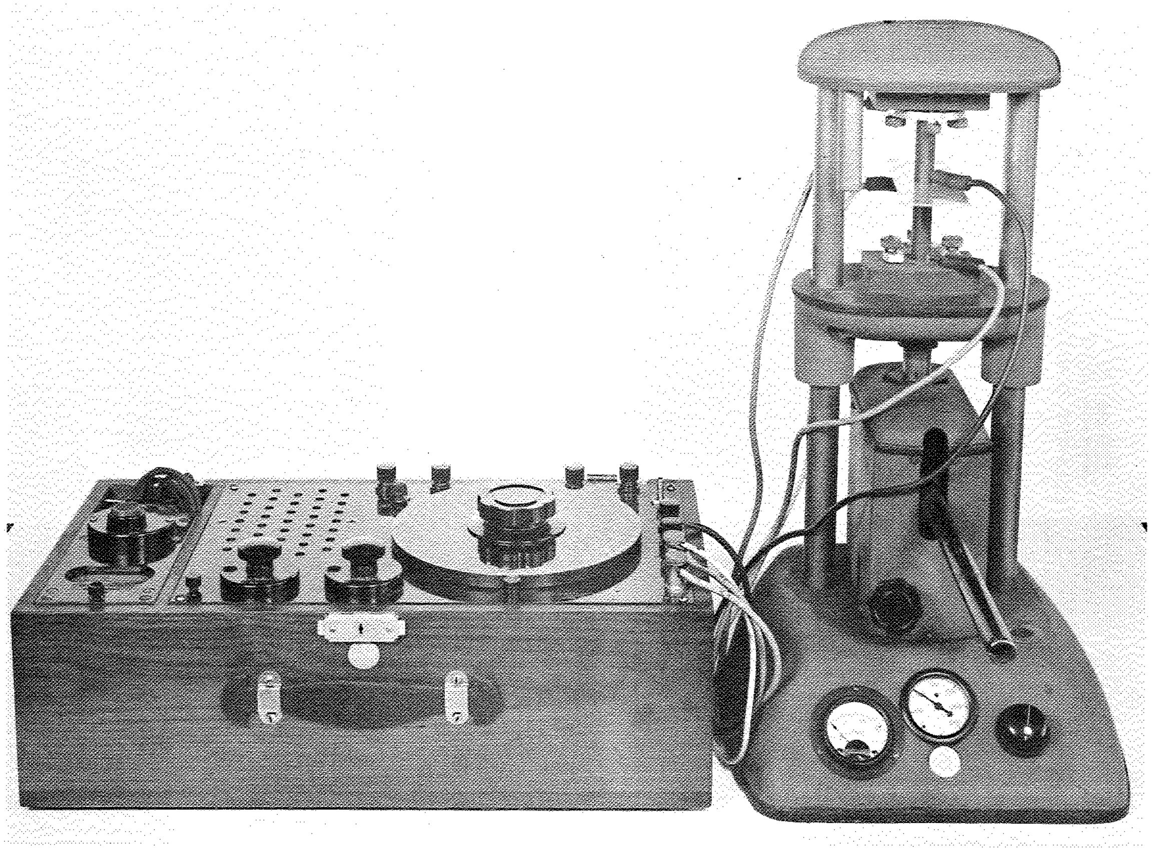


Figure 9 - Apparatus for measuring surface resistance

FIGURE 10
CURRENT FLOW
2219-T87 COUPLES

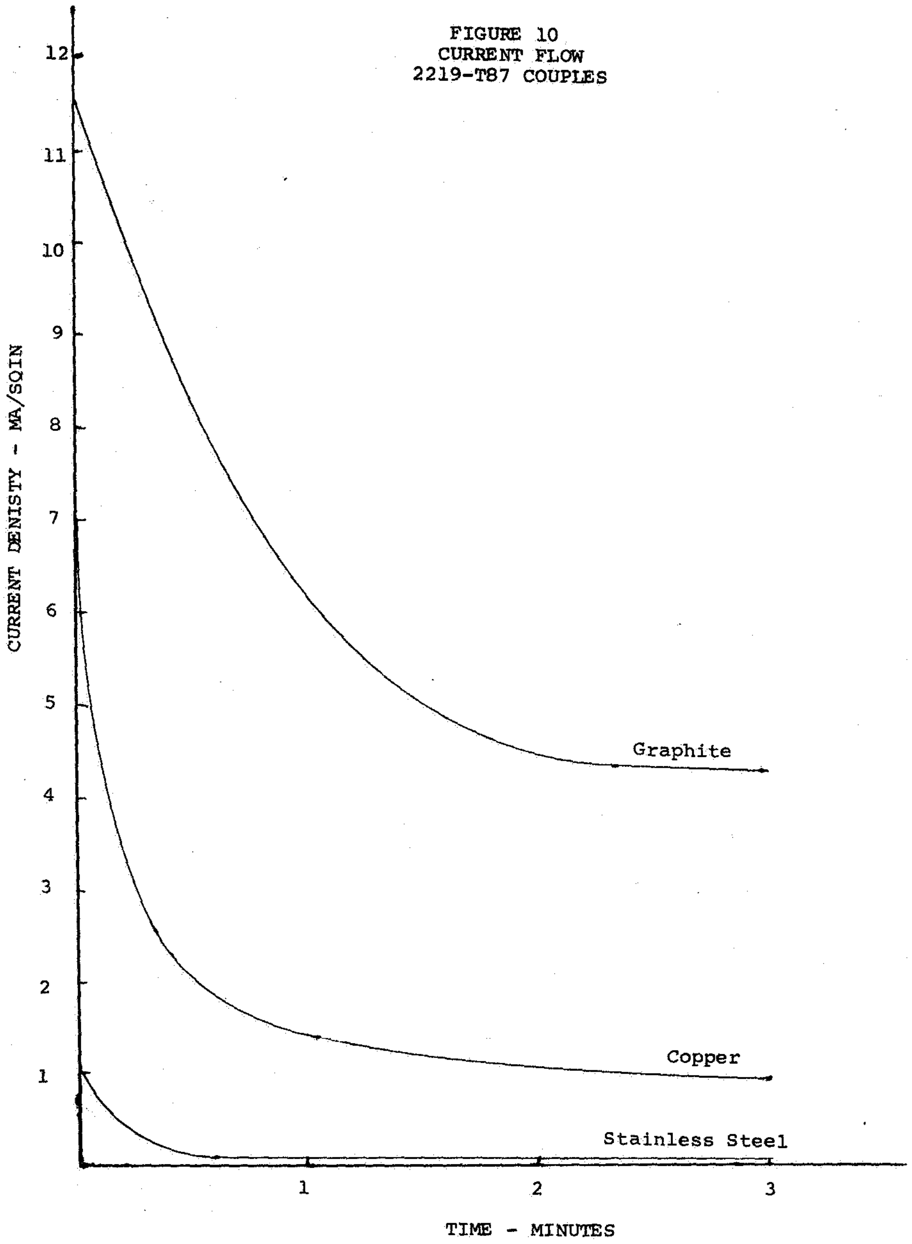


FIGURE 11
POTENTIAL-CURRENT DENSITY
2219-T87 COUPLES

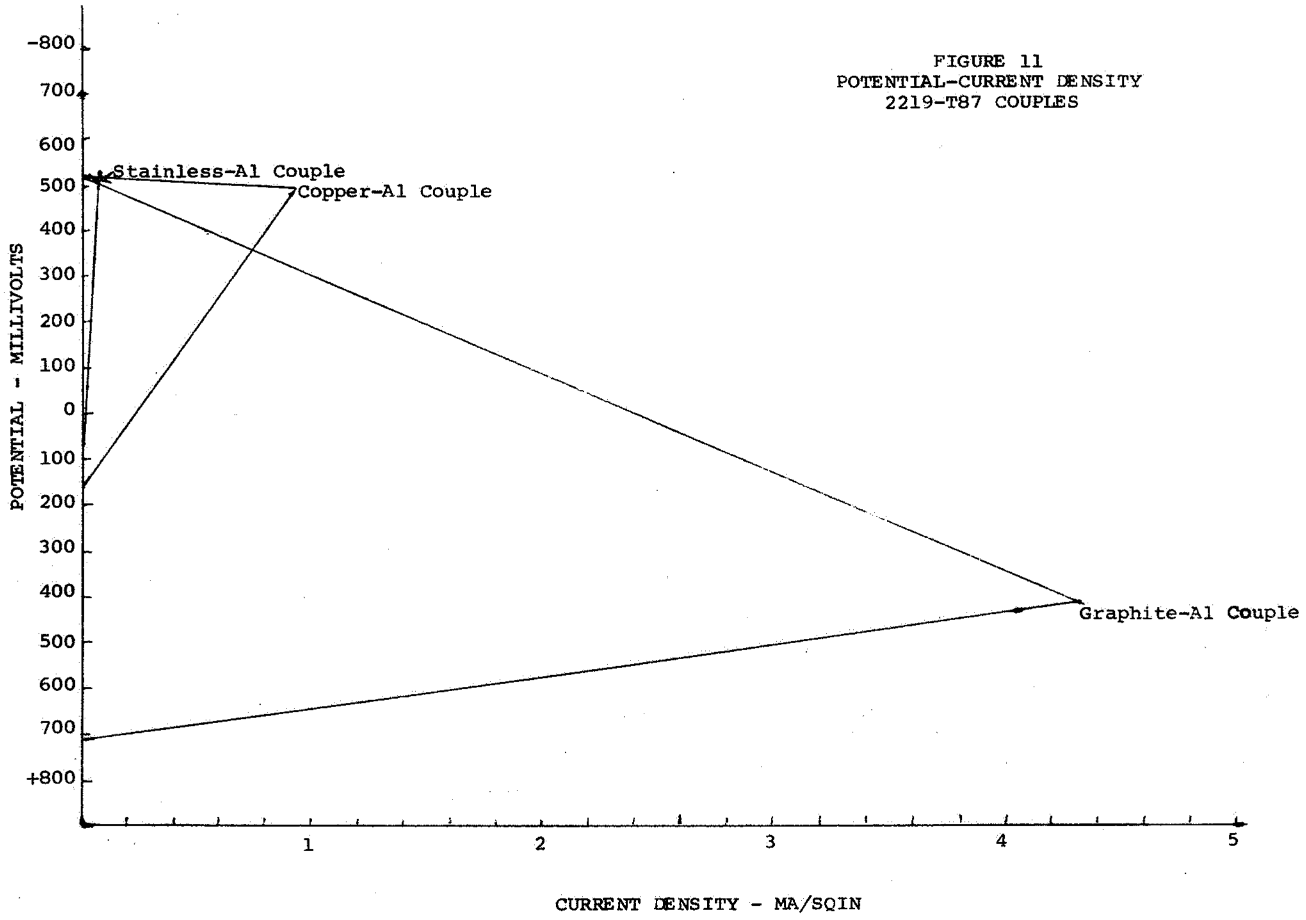


FIGURE 12
HEXAVALENT CHROMIUM VS STORAGE TIME
FIRST DAY LEACH

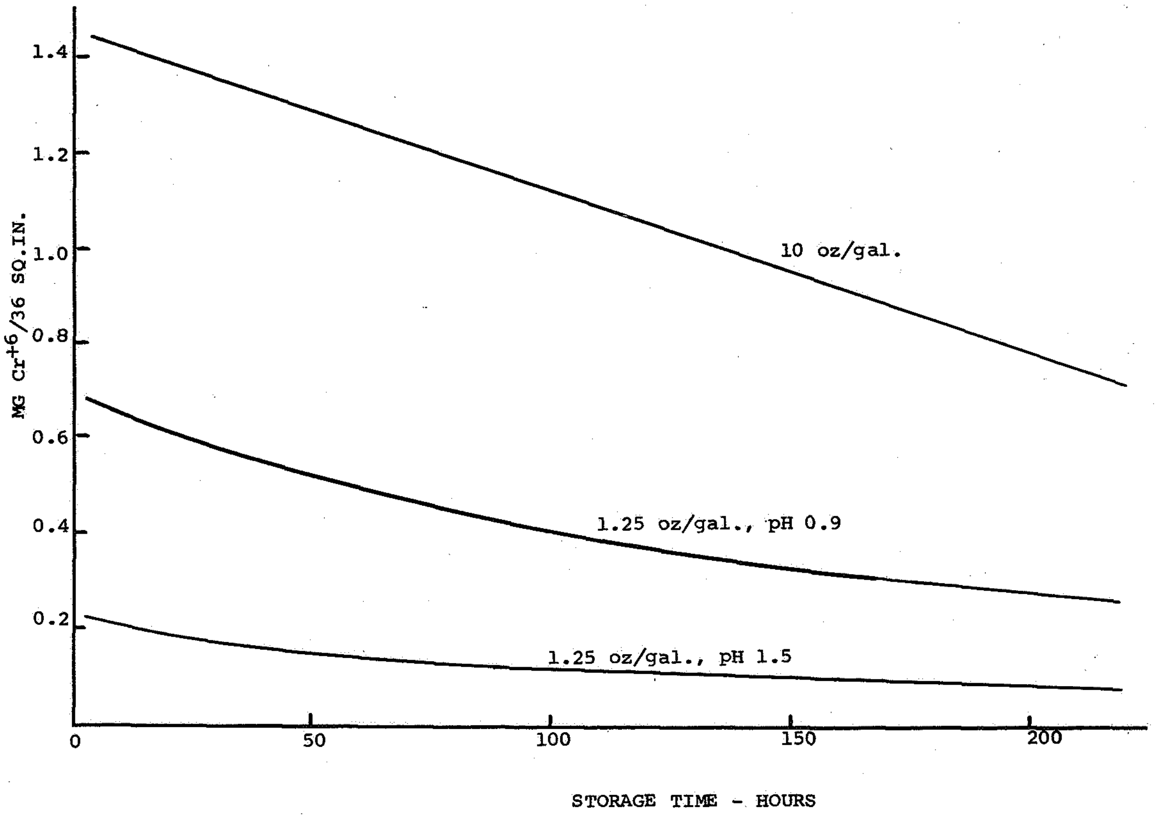


FIGURE 13
HEXAVALENT CHROMIUM VS LEACH INTERVAL
COATING AGED FOR TWO HOURS

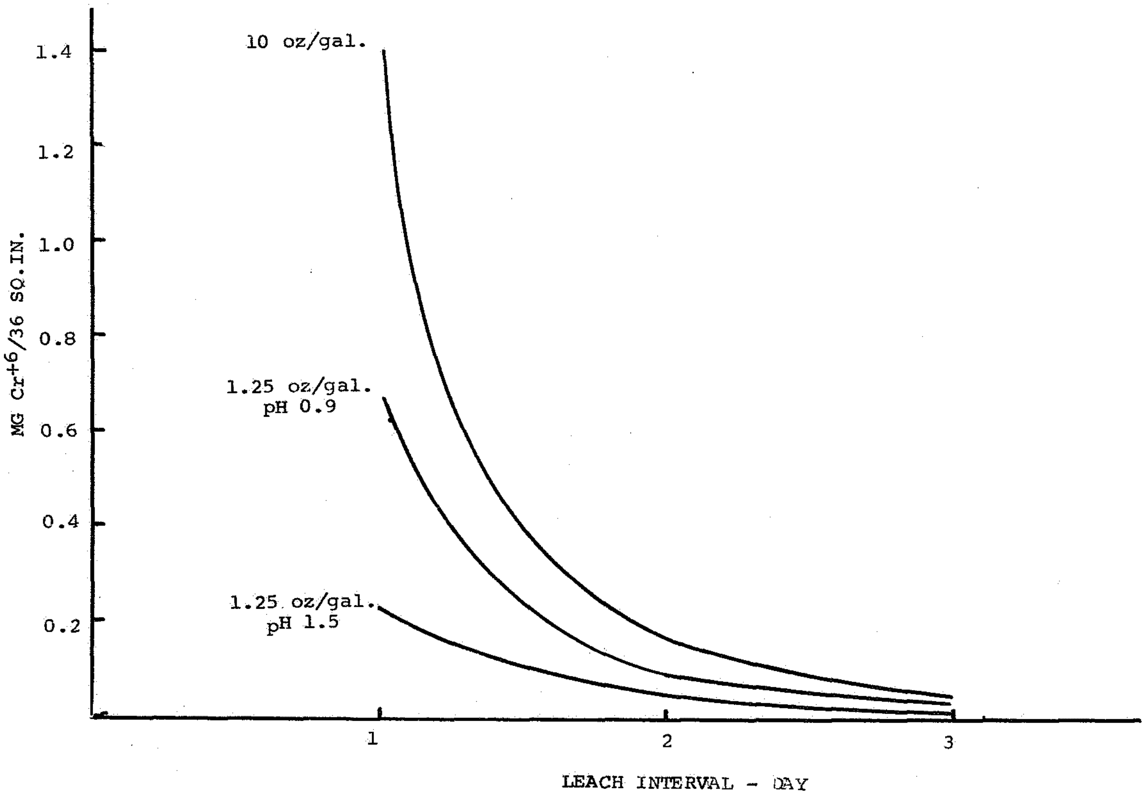


FIGURE 14
HEXAVALENT CHROMIUM VS LEACH INTERVAL
10 OZ/GAL. IRIDITE COATING

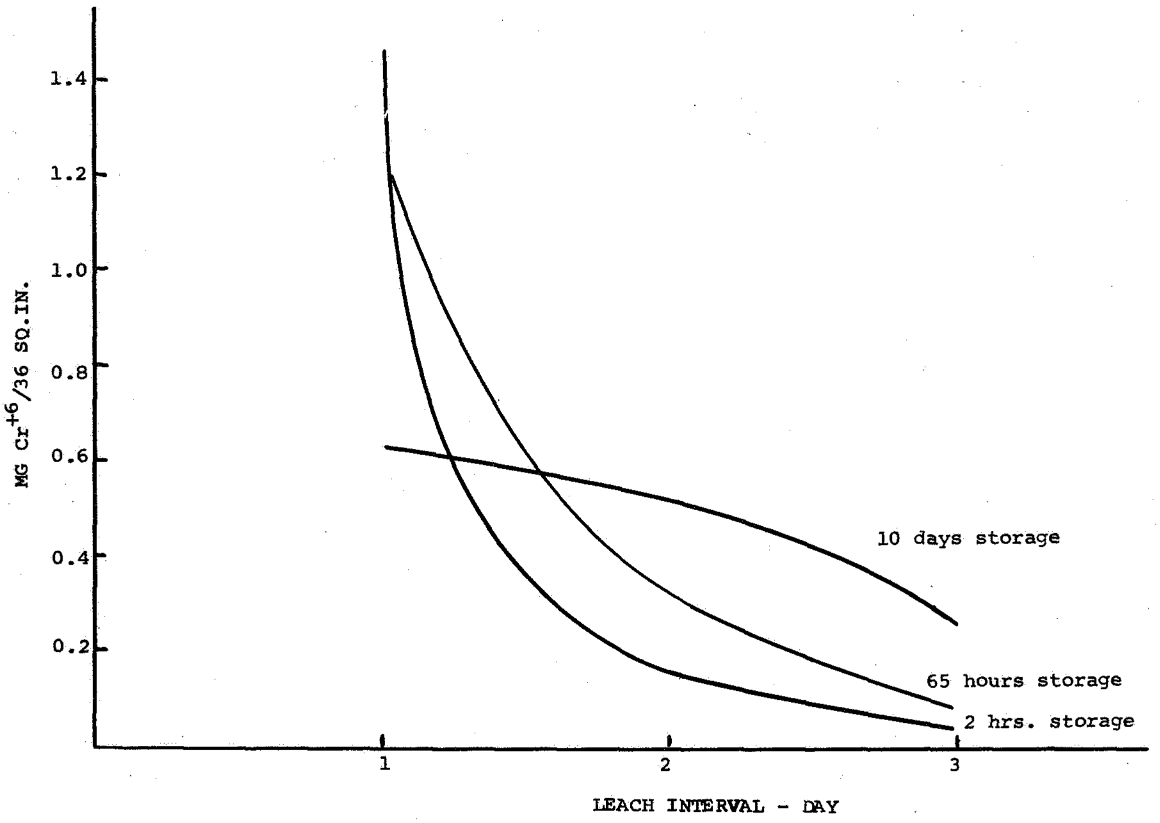
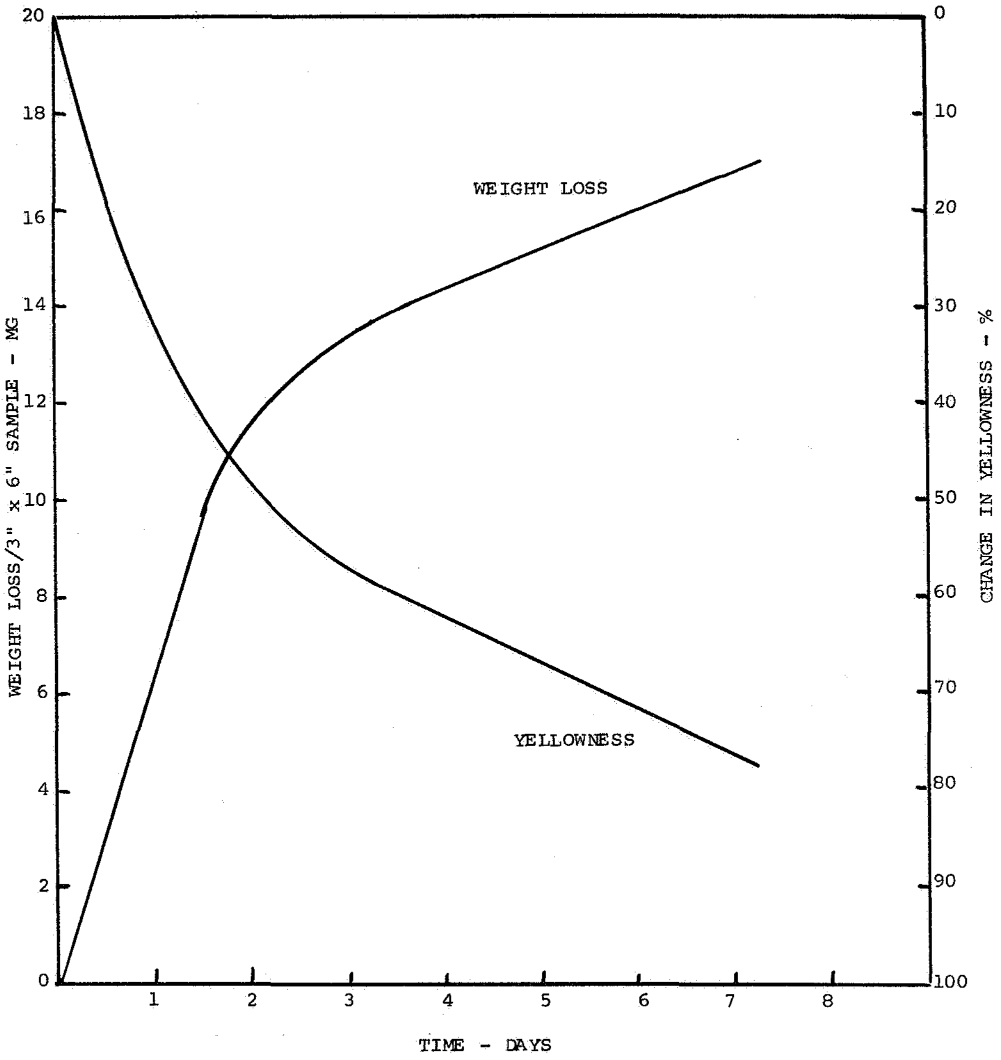
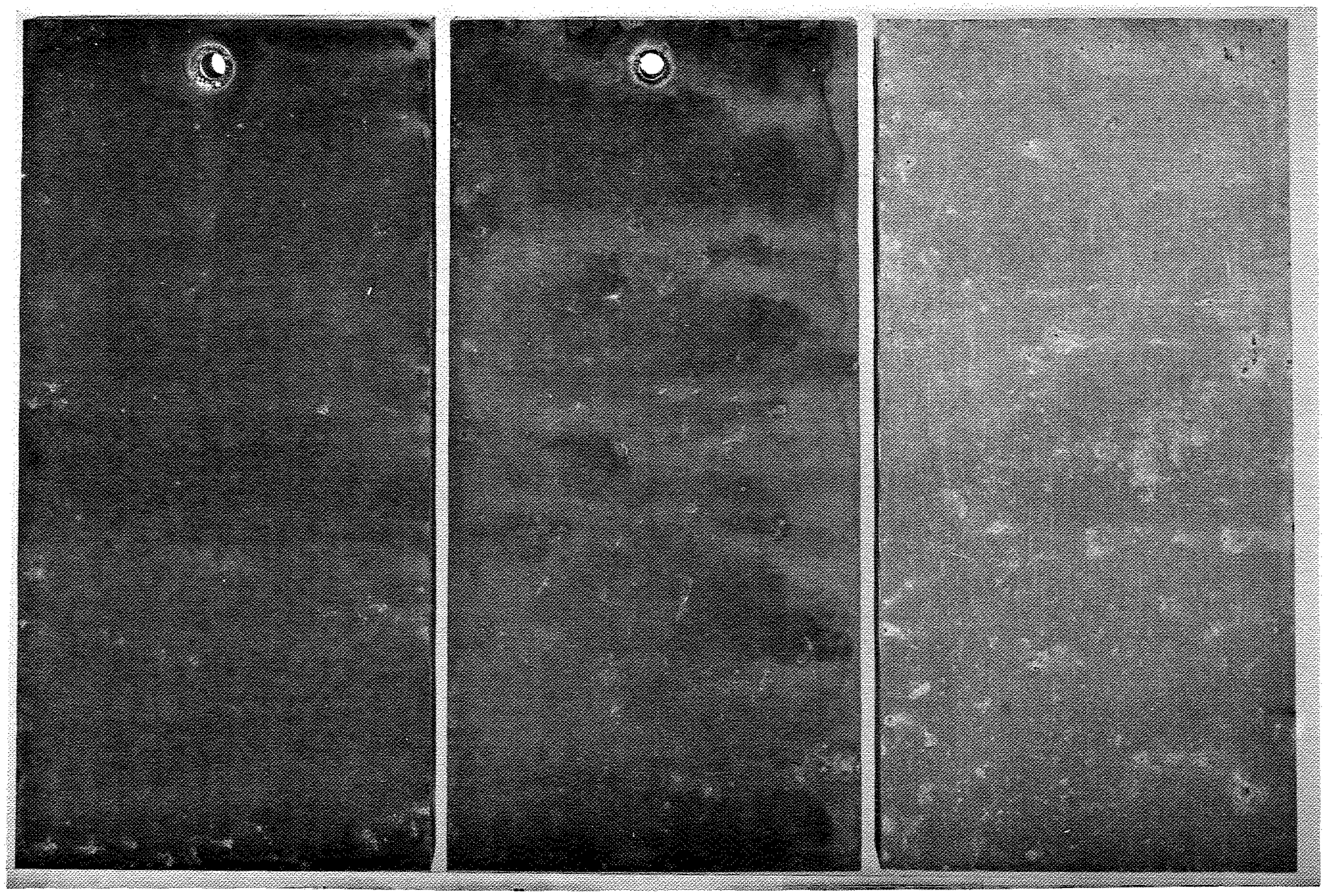


FIGURE 15
YELLOWNESS AND WEIGHT LOSS VS EXPOSURE TIME



PEH095J



0.50" INITIAL 10 oz/gal

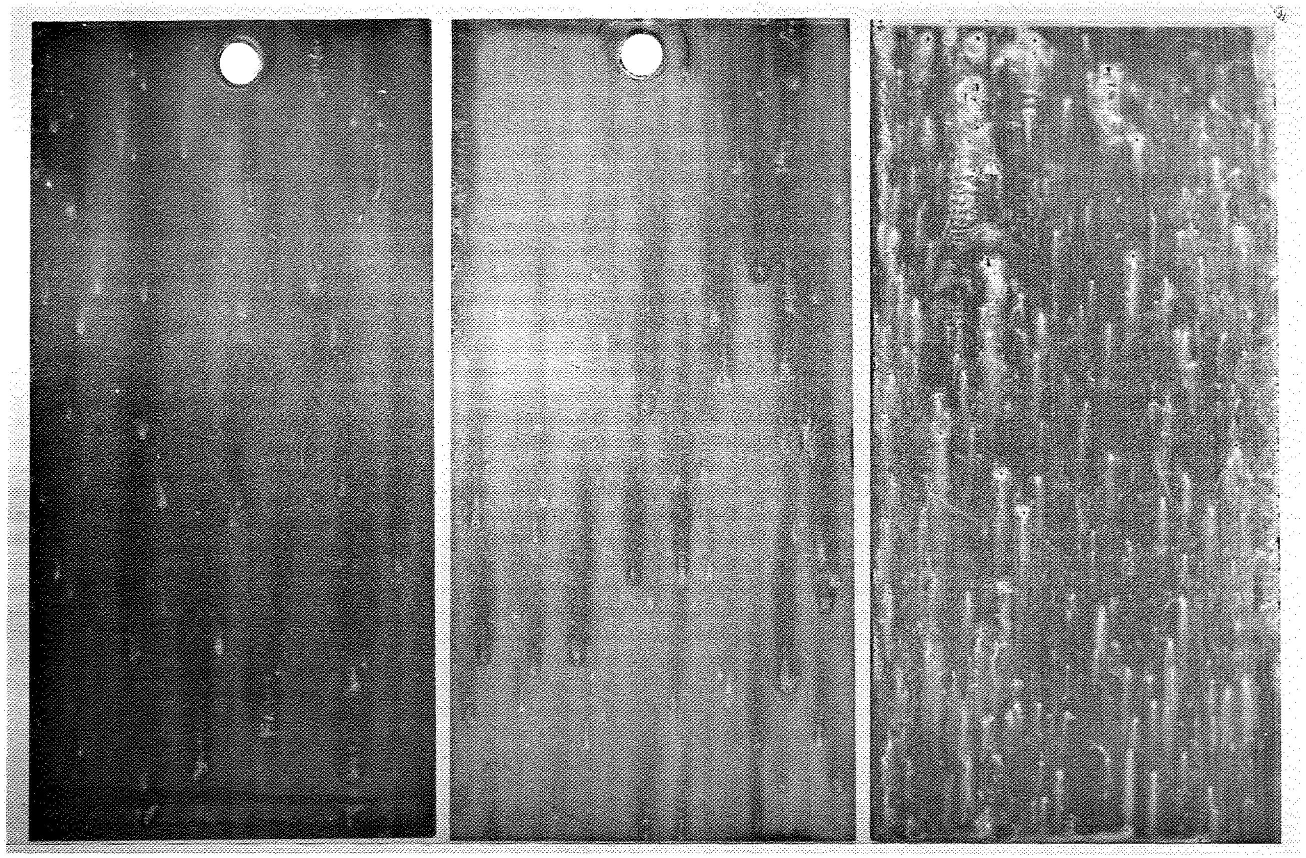
0.50" AFTER 10 ft^2/gal 10 oz/gal

0.50" INITIAL 1.25 oz/gal

FIGURE 16 - PILOT PLANT TEST

168 HOURS SALT SPRAY EXPOSURE

PEH096J



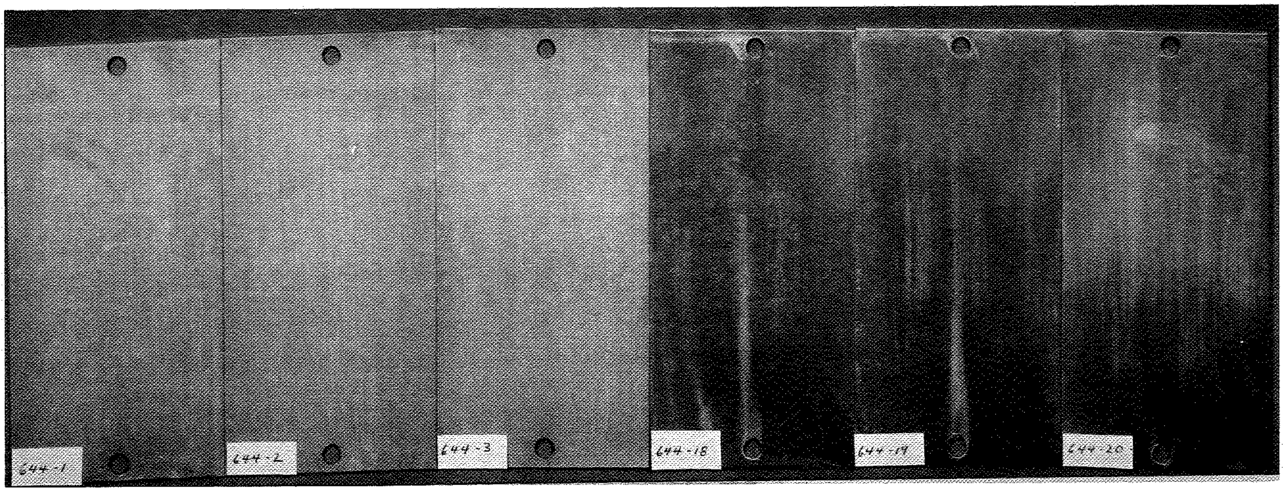
0.125" INITIAL 10 oz/gal

0.125" AFTER 10 ft^2/gal 10 oz/gal

0.125" INITIAL 1.25 oz/gal

FIGURE 17 - PILOT PLANT TEST

168 HOURS SALT SPRAY EXPOSURE



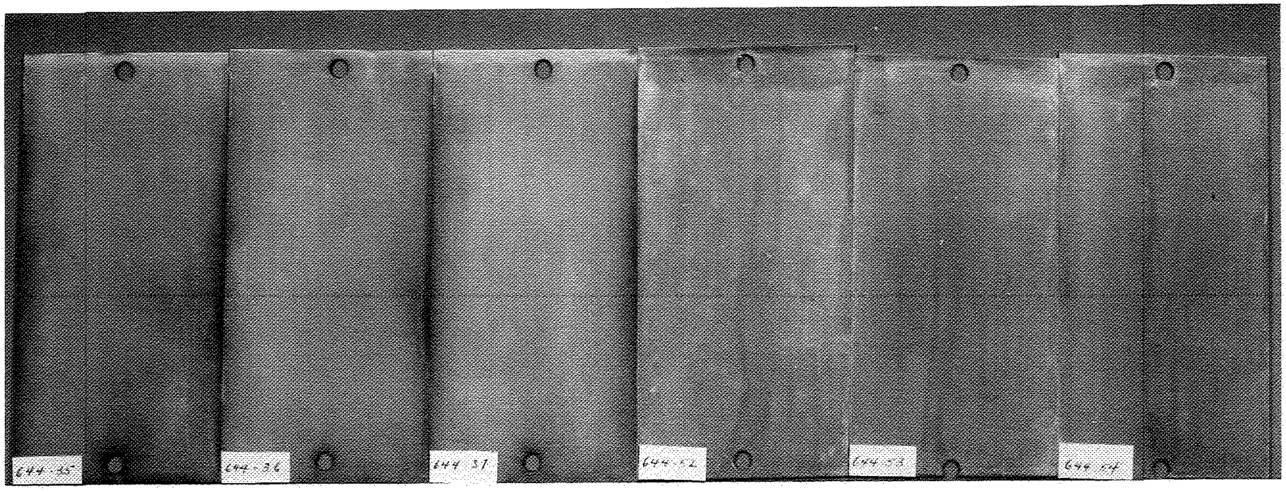
5052-H38
1.25 oz/gal Iridite at pH 1.5

5052-H38
Scotch Brite + 1.25 oz/gal Iridite

Salt spray test No. 1
168 hours exposure

Figure 18

PDC203CJ

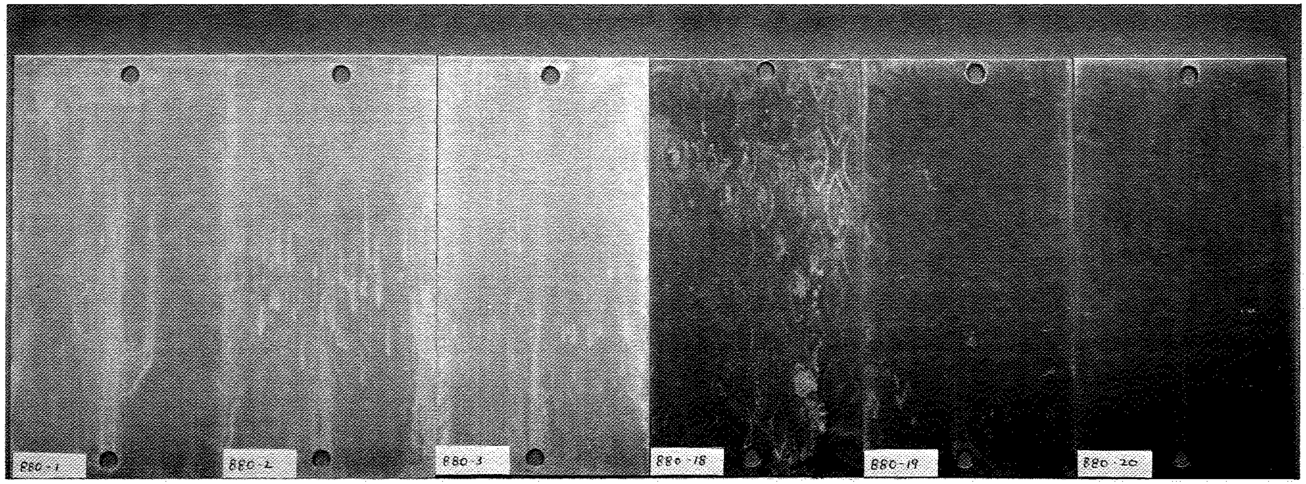


5052-H38
1.25 oz/gal Iridite at pH 0.9

5052-H38
6 oz/gal Iridite

Salt spray test No. 1
168 hours exposure

Figure 19

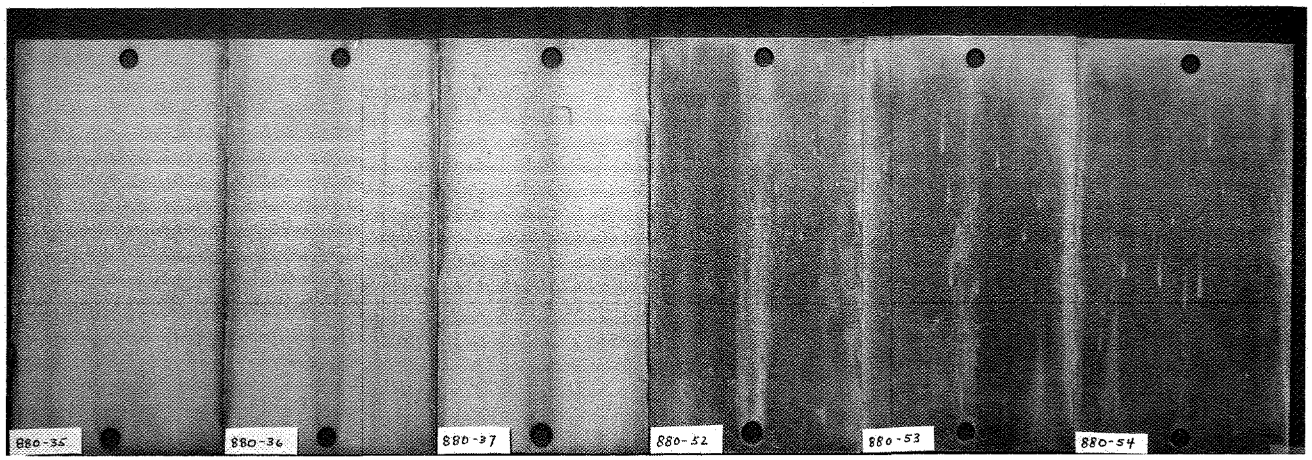


7075-T6
1.25 oz/gal Iridite at pH 1.5

7075-T6
Scotch Brite + 1.25 oz/gal Iridite

Salt spray test No. 1
168 hours exposure

Figure 20



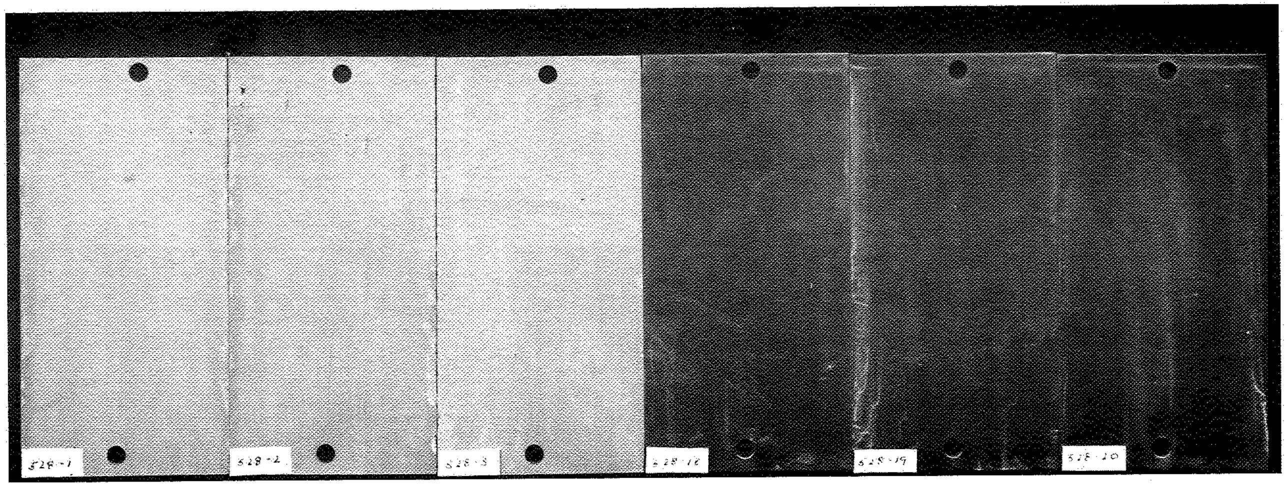
7075-T6
1.25 oz/gal Iridite at pH 0.9

7075-T6
6 oz/gal Iridite

Salt spray test No. 1
168 hours exposure

Figure 21

PDD105CJ

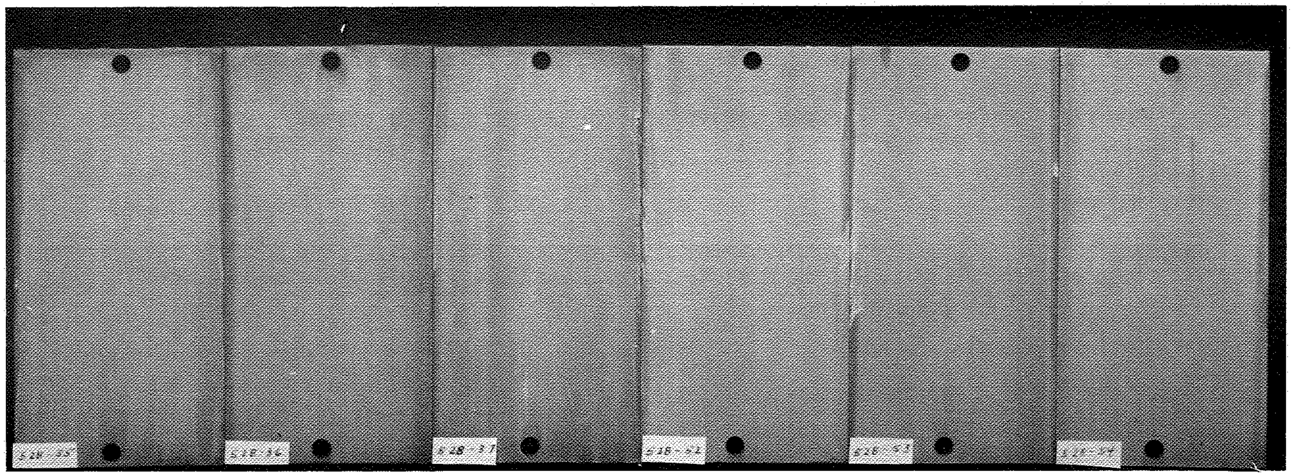


2014-T6
1.25 oz/gal. Iridite at pH 1.5

2014-T6
Scotch Brite + 1.25 oz/gal. Iridite

Salt Spray Test No. 2
168 Hours Exposure

Figure 22

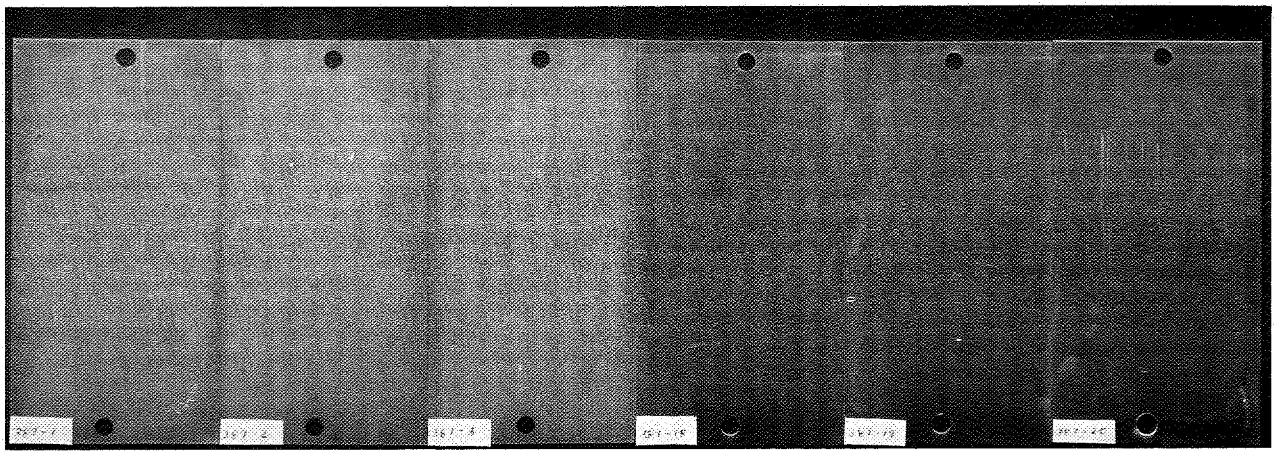


2014-T6
1.25 oz/gal. Iridite at pH 0.9

2014-T6
6 oz/gal. Iridite

Salt Spray Test No. 2
168 Hours Exposure

Figure 23

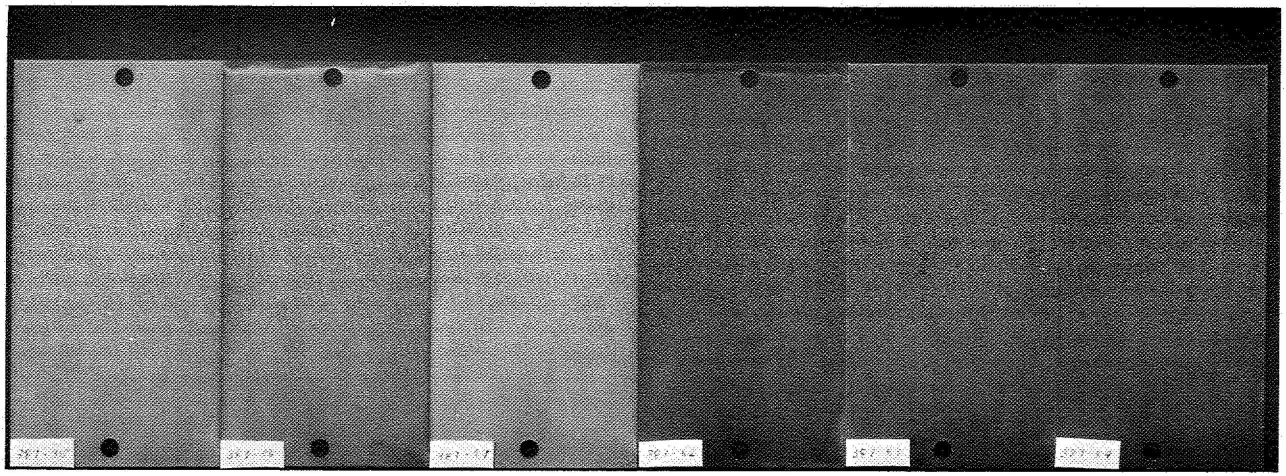


6061-T6
1.25 oz/gal. Iridite at pH 1.5

6061-T6
Scotch Brite + 1.25 oz/gal. Iridite

Salt Spray Test No. 2
168 Hours Exposure

Figure 24

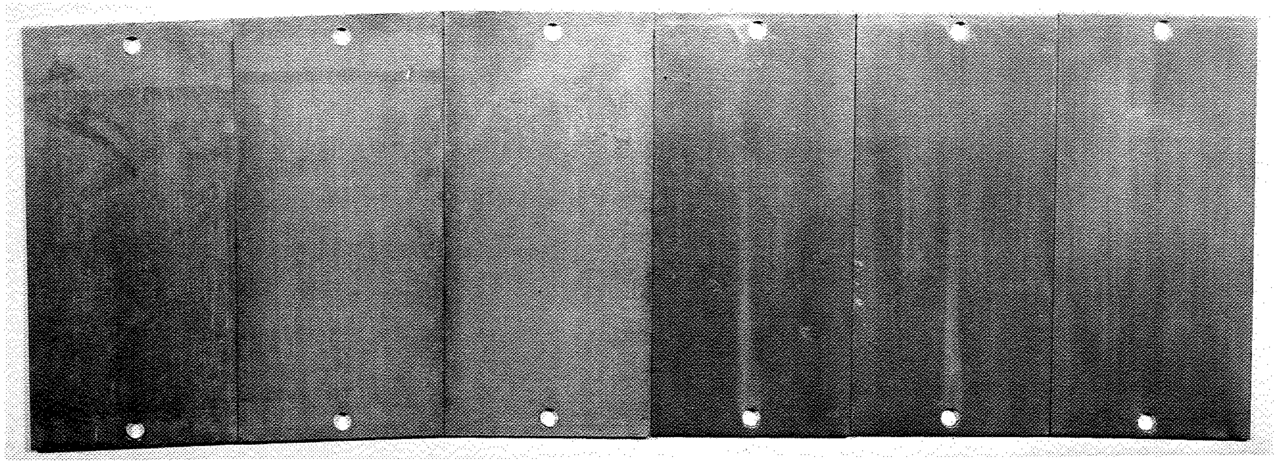


6061-T6
1.25 oz/gal. Iridite at pH 0.9

6061-T6
6 oz/gal. Iridite

Salt Spray Test No. 2
168 Hours Exposure

Figure 25

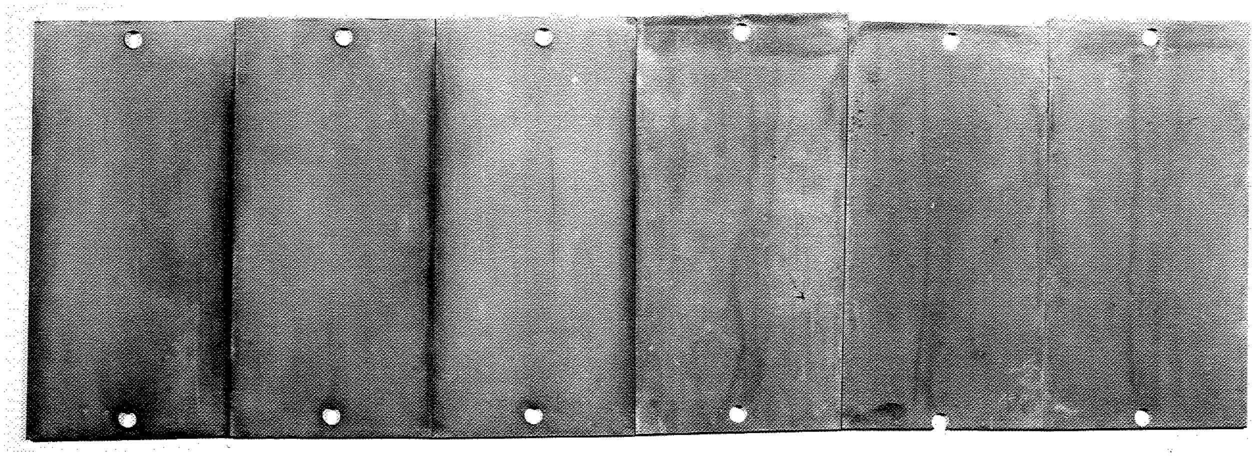


5052-H38
1.25 oz/gal. Iridite at pH 1.5

5052-H38
Scotch Brite + 1.25 oz/gal. Iridite

FIGURE 26 - 336 HOURS SALT SPRAY
EXPOSURE

PDF015CJ

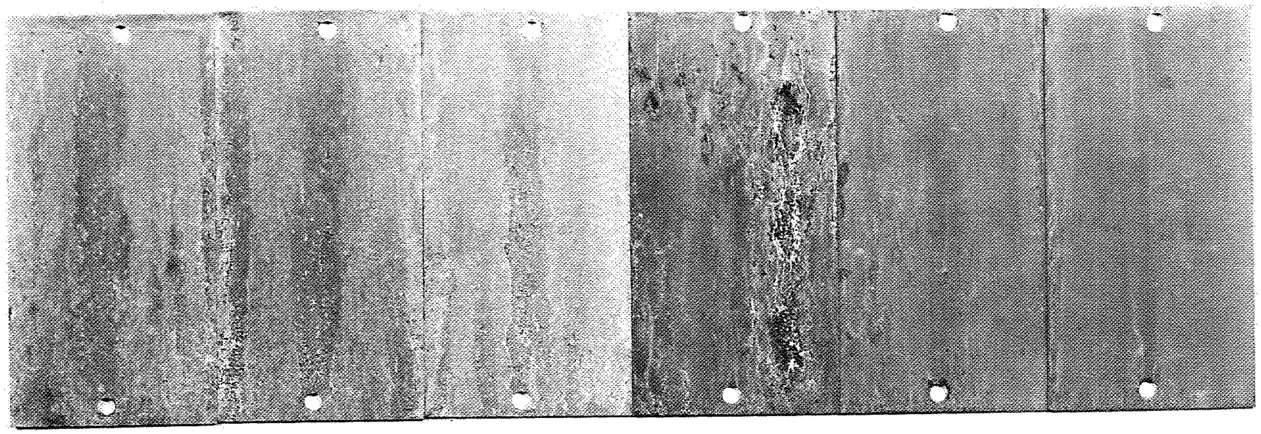


5052-H28
1.25 oz/gal. Iridite at pH 0.9

5052-H38
6 oz/gal. Iridite

FIGURE 27 - 336 HOURS SALT SPRAY EXPOSURE

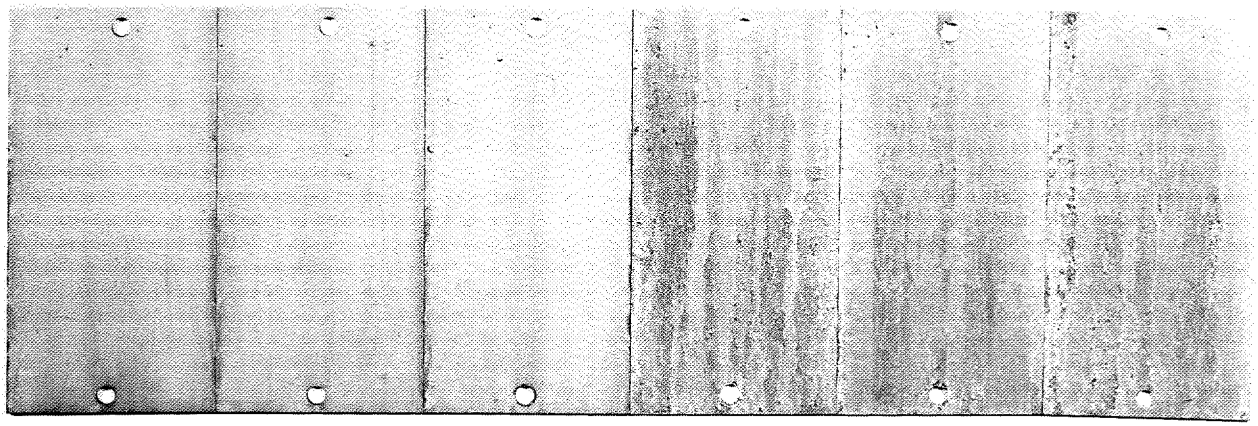
PDF016CJ



7075-T6
1.25 oz/gal. Iridite at pH 1.5

7075-T6
Scotch Brite + 1.25 oz/gal. Iridite

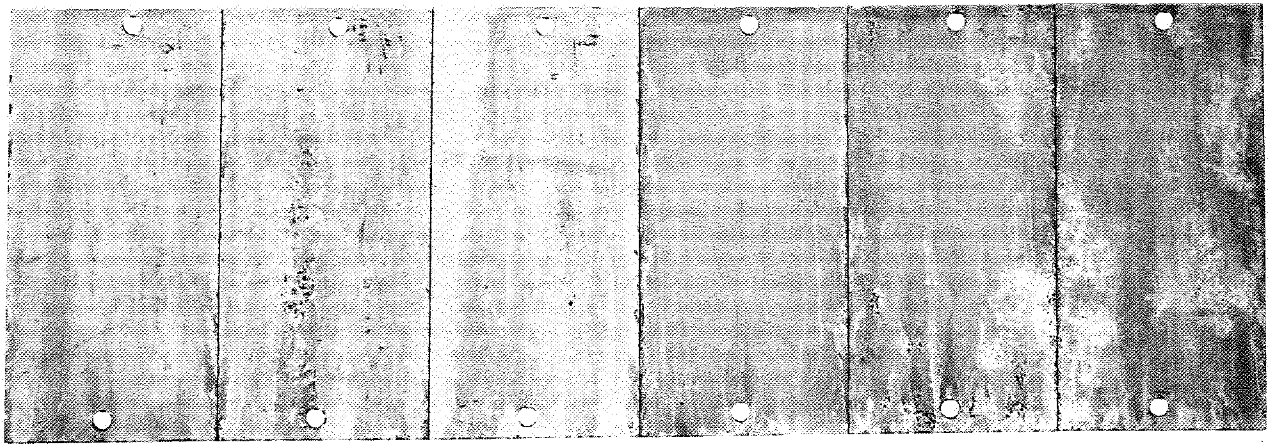
FIGURE 28 - 336 HOURS SALT SPRAY
EXPOSURE



7075-T6
1.25 oz/gal. Iridite at pH 0.9

7075-T6
6 oz/gal. Iridite

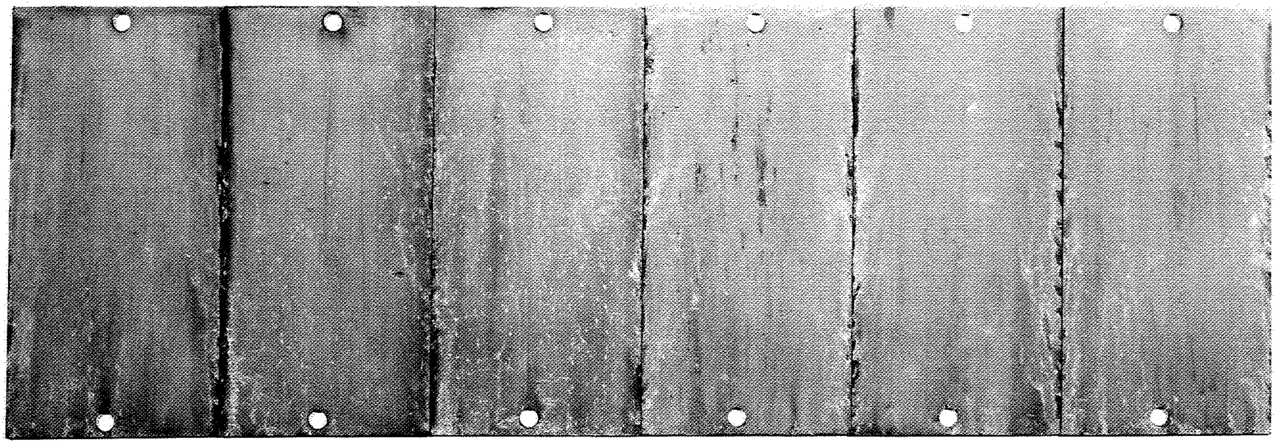
FIGURE 29 - 336 HOURS SALT SPRAY EXPOSURE



2014-T6
1.25 oz/gal. Iridite at pH 1.5

2014-T6
Scotch Brite + 1.25 oz/gal. Iridite

FIGURE 30 - 336 HOURS SALT SPRAY EXPOSURE

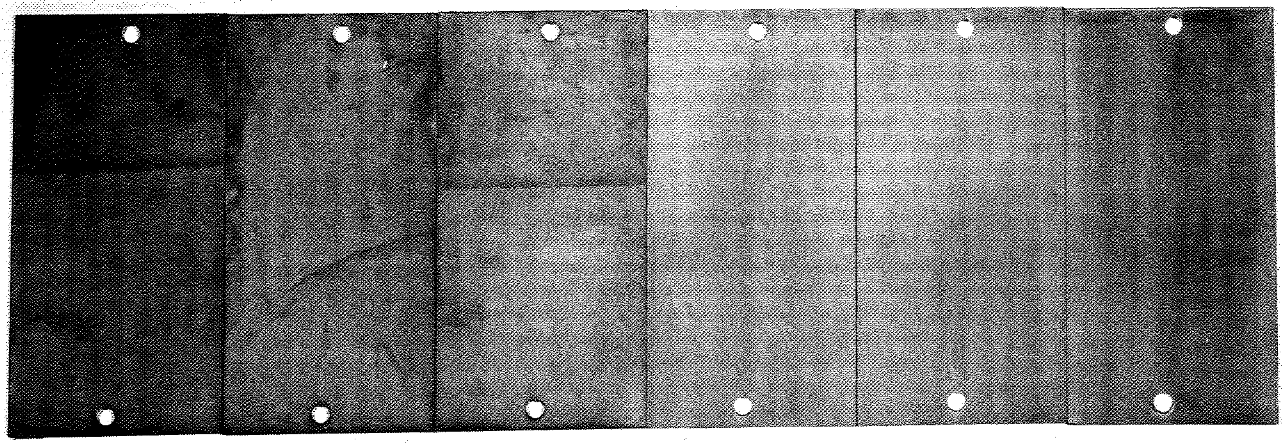


2014-T6
1.25 oz/gal. Iridite at pH 0.9

2014-T6
6 oz/gal. Iridite

FIGURE 31 - 336 HOURS SALT SPRAY EXPOSURE

PDG102CJ

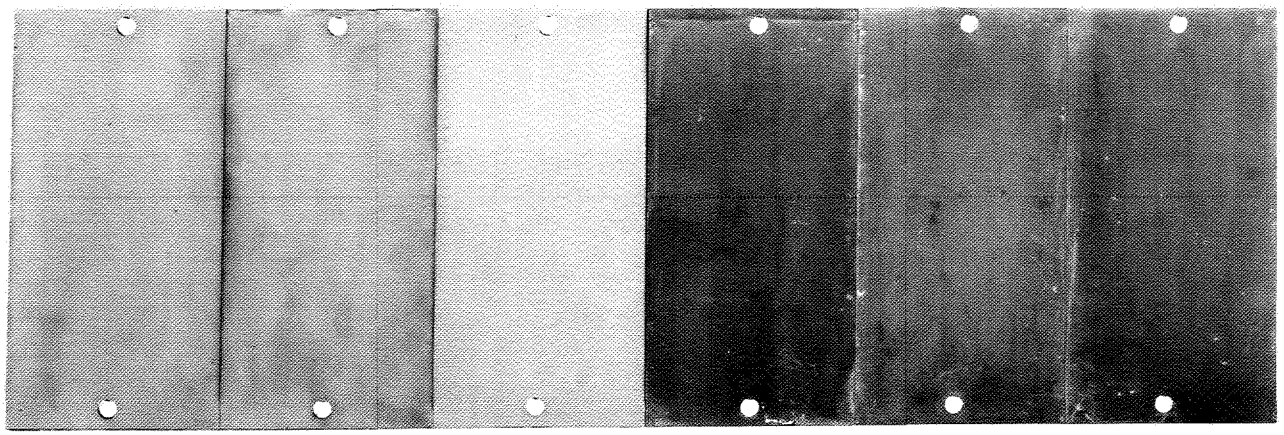


6061-T6
1.25 oz/gal. Iridite at pH 1.5

6061-T6
Scotch Brite + 1.25 oz/gal. Iridite

FIGURE 32 - 336 HOURS SALT SPRAY
EXPOSURE

PDG103CJ

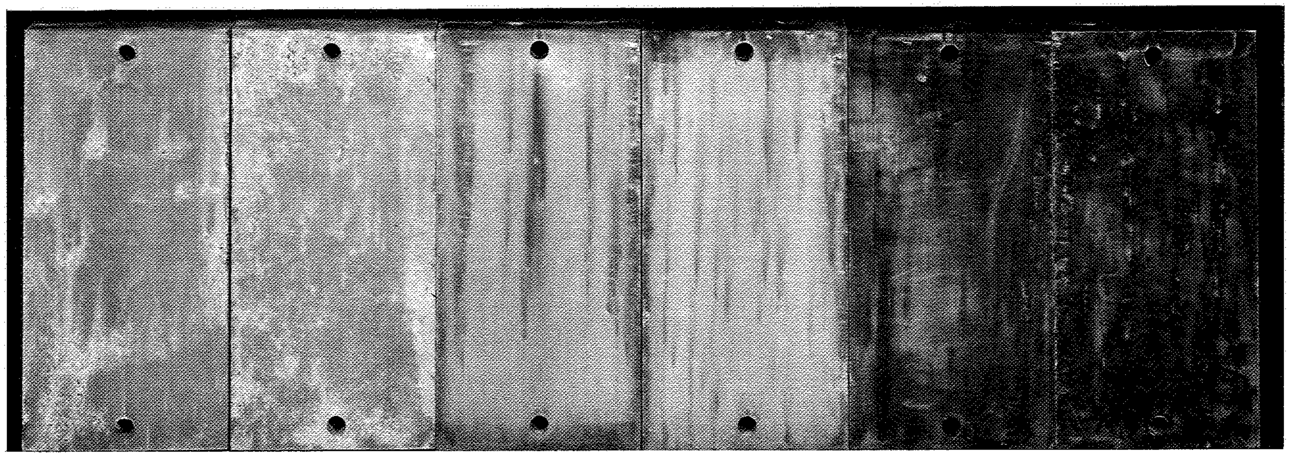


6061-T6
1.25 oz/gal. Iridite at pH 0.9

6061-T6
6 oz/gal. Iridite

FIGURE 33 - 336 HOURS SALT SPRAY
EXPOSURE

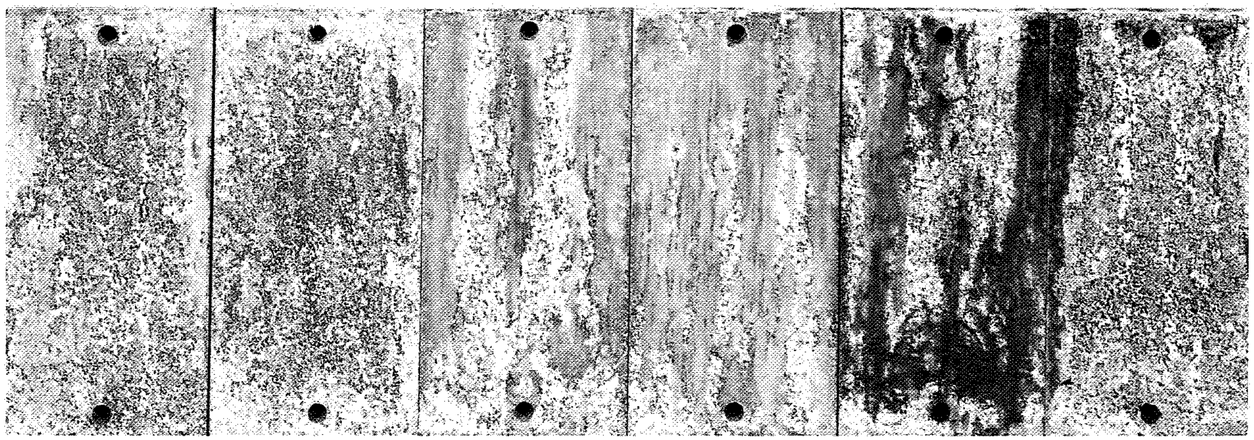
PDD148CJ



Salt Spray Test No. 3
168 Hours Exposure

Figure 34

PDG070CJ



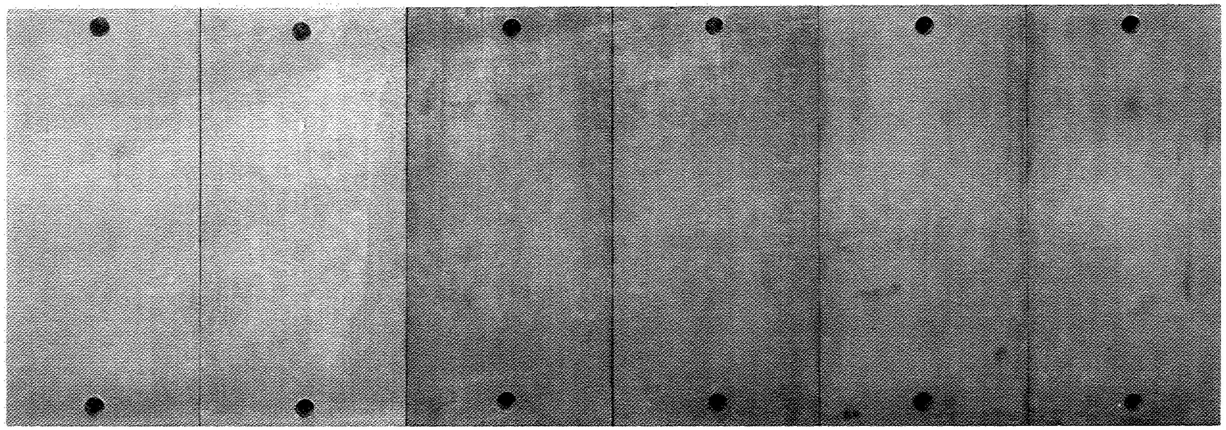
2219-F
1.25 oz/gal., pH 1.5

2219-F
1.25 oz/gal., pH 0.9

2219-F
6 oz/gal., pH 0.7

FIGURE 35 - 336 HOURS SALT SPRAY EXPOSURE

PDD264CJ

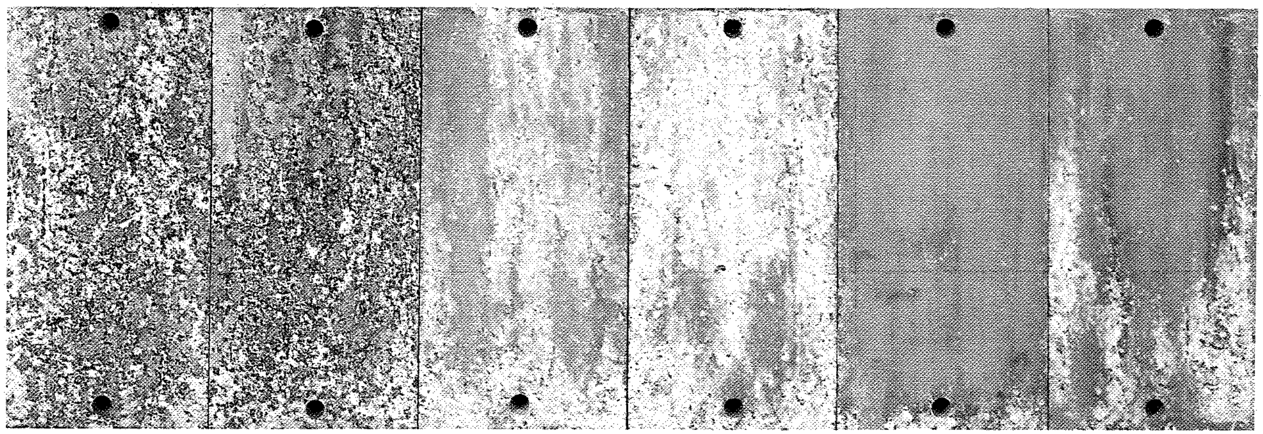


2219-T62
1.25 oz/gal., pH 1.5

2219-T62
1.25 oz/gal., pH 0.9

2219-T62
6 oz/gal., pH 0.7

FIGURE 36 - SALT SPRAY TEST NO. 5
168 HOURS EXPOSURE



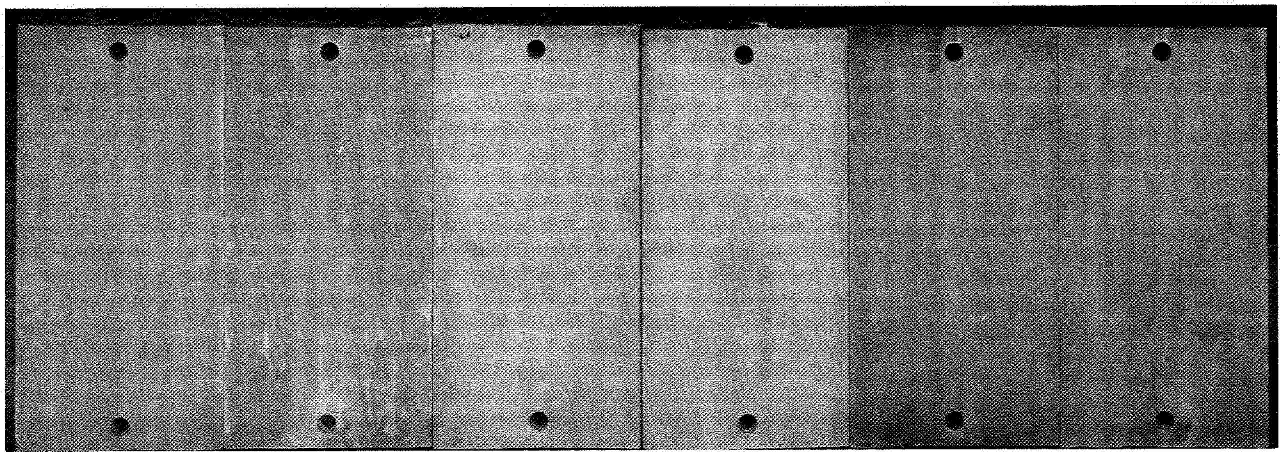
2219-T62
1.25 oz/gal., pH 1.5

2219-T62
1.25 oz/gal., pH 0.9

2219-T62
6 oz/gal., pH 0.7

FIGURE 37 - 336 HOURS SALT SPRAY
EXPOSURE

PDD147CJ



2219-T37
1.25 oz/gal., pH 1.5

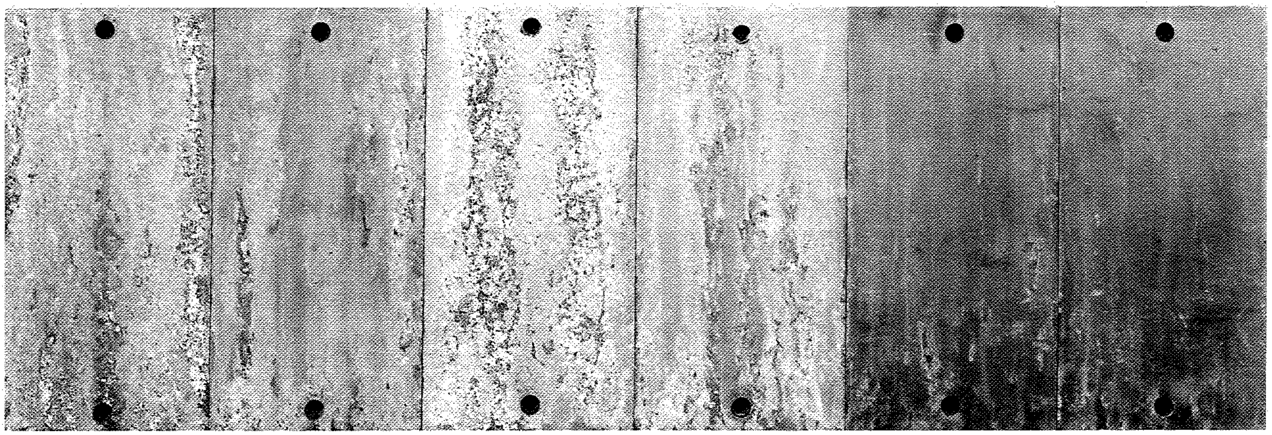
2219-T37
1.25 oz/gal., pH 0.9

2219-T37
6 oz/gal., pH 0.7

Salt Spray Test No. 3
168 Hours Exposure

Figure 38

PDG069CJ



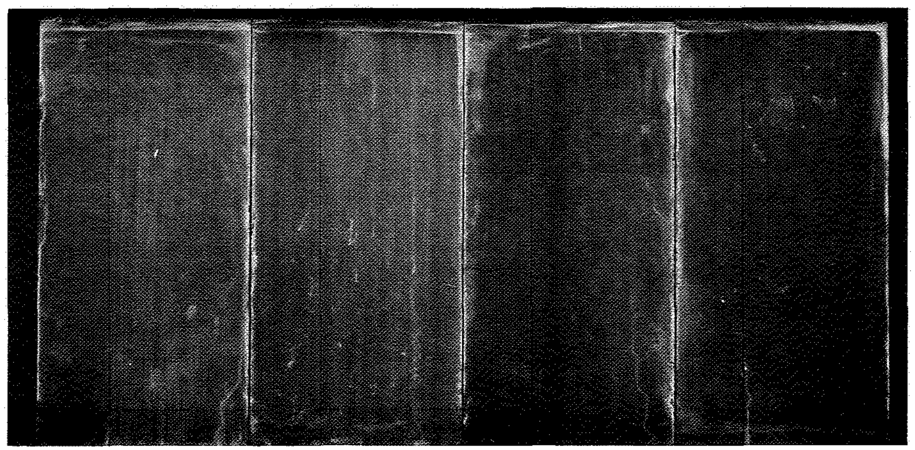
2219-T37
1.25 oz/gal., pH 1.5

2219-T37
1.25 oz/gal., pH 0.9

2219-T37
6 oz/gal., pH 0.7

FIGURE 39 - 336 HOURS SALT SPRAY
EXPOSURE

PDD150CJ

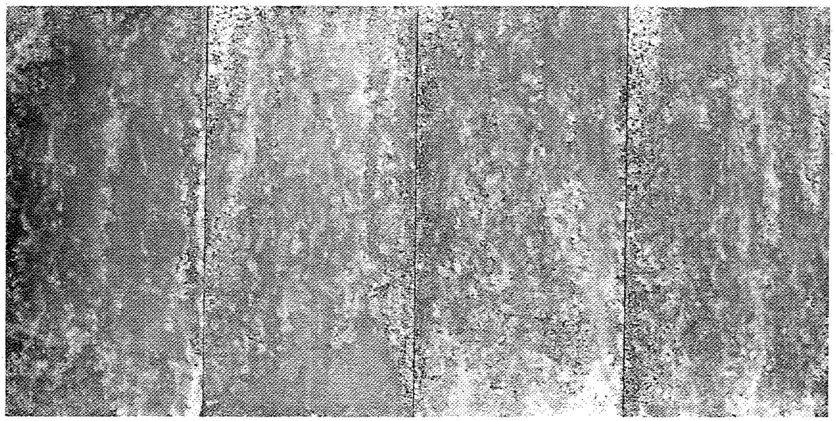


2219-T87
Machined - Outer Surface
1.25 oz/gal., pH 1.5

2219-T87
Machined - Inner Surface
1.25 oz/gal., pH 1.5

Salt Spray Test No. 3
168 Hours Exposure

Figure 40

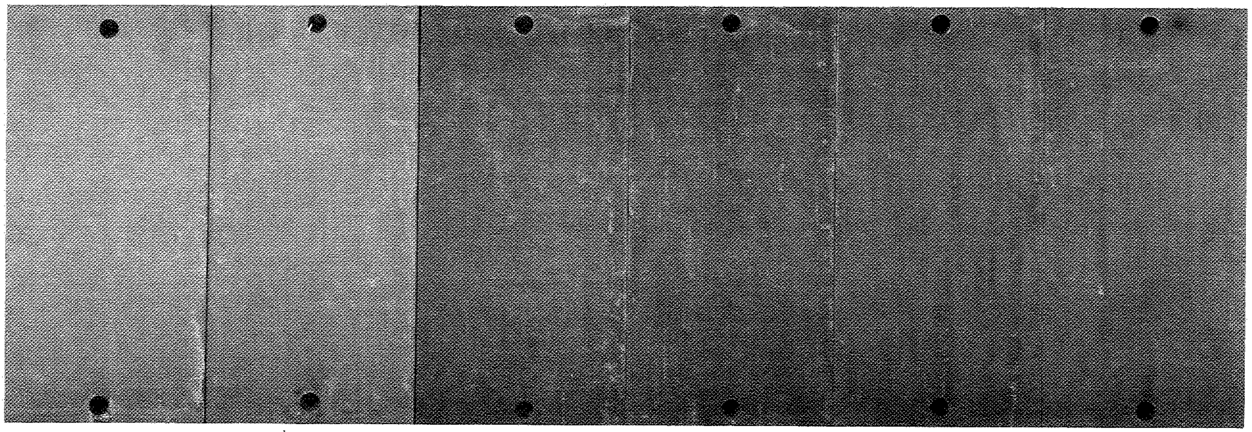


Outer Surface Inner Surface Outer Surface Inner Surface

Machined 2219-T87 - 1.25 oz/gal. Iridite at pH 1.5

FIGURE 41 - 336 HOURS SALT SPRAY EXPOSURE

PDD262CJ



2219-T87
H_2SO_4-CrO_3 Etch
1.25 oz/gal., pH 1.5

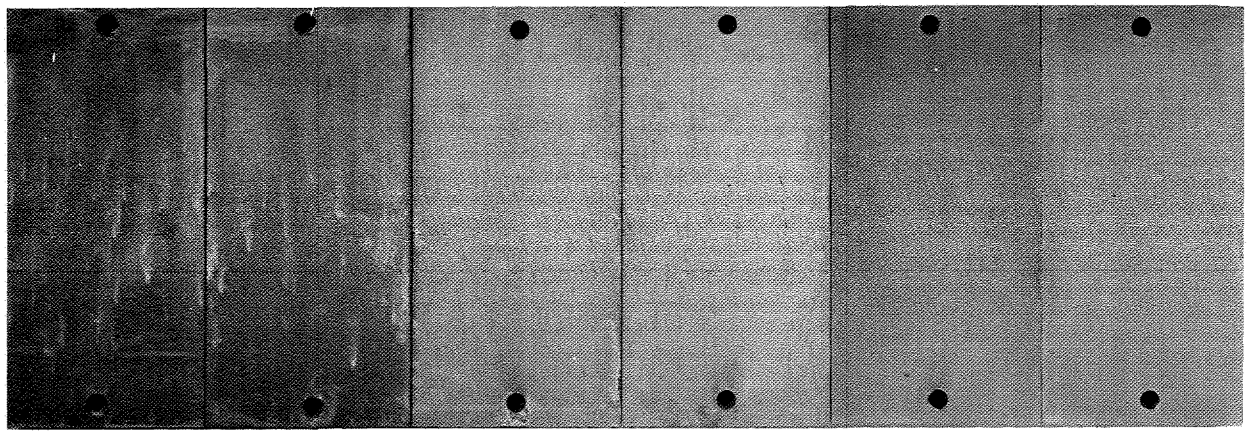
2219-T87
H_2SO_4-CrO_3 Etch
1.25 oz/gal., pH 0.9

2219-T87
H_2SO_4-CrO_3 Etch
6 oz/gal., pH 0.7

SALT SPRAY TEST NO. 4
168 HOURS EXPOSURE

FIGURE 42

PDD263CJ



2219-T87
Chem Milled
1.25 oz/gal., pH 1.5

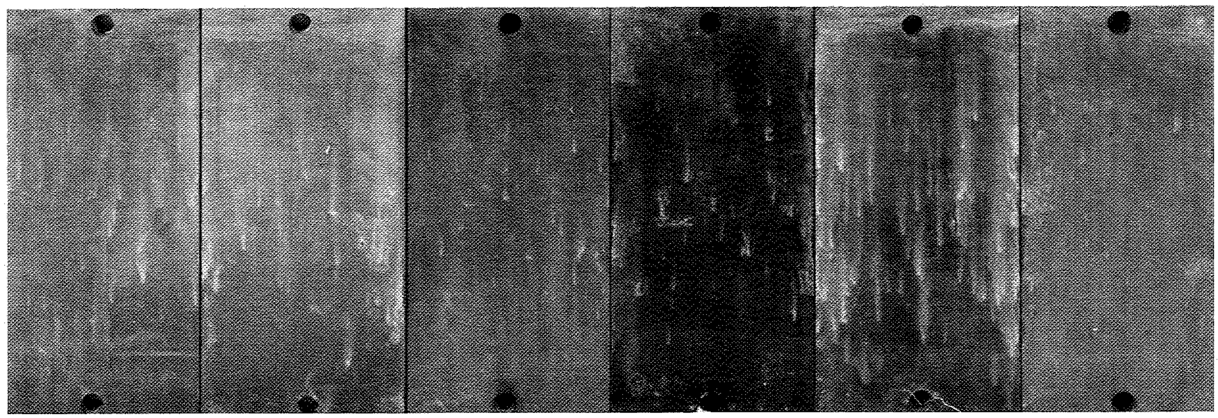
2219-T87
H_2SO_4-CrO_3 Etch
1.25 oz/gal., pH 1.5

2219-T87
Machined
1.25 oz/gal., pH 1.5

SALT SPRAY TEST NO. 4
168 HOURS EXPOSURE

FIGURE 43

PDD261CJ



2219-T87
Chem Milled
1.25 oz/gal., pH 1.5

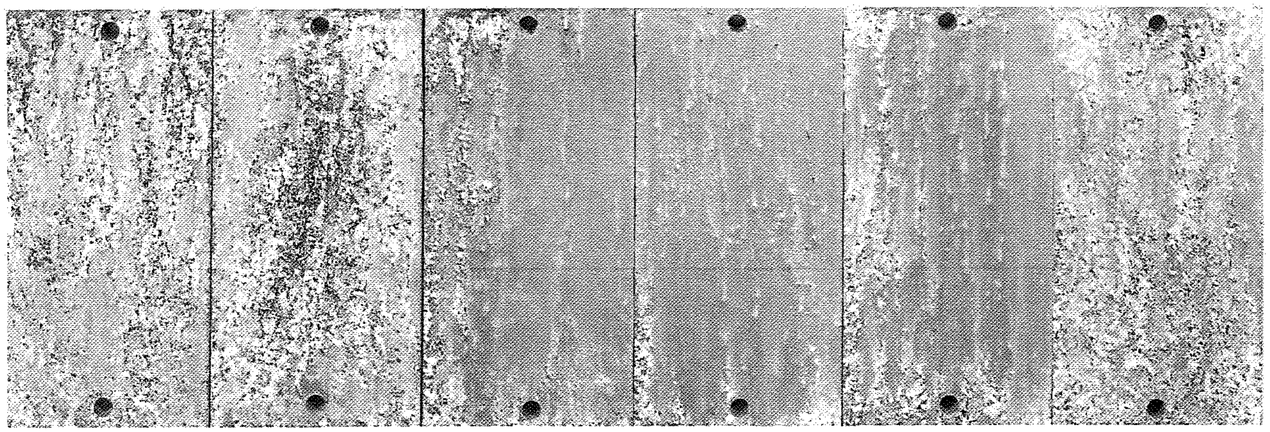
2219-T87
Chem Milled
1.25 oz/gal., pH 0.9

2219-T87
Chem Milled
6 oz/gal., pH 0.7

SALT SPRAY TEST NO. 4
168 HOURS EXPOSURE

FIGURE 44

PDG064CJ

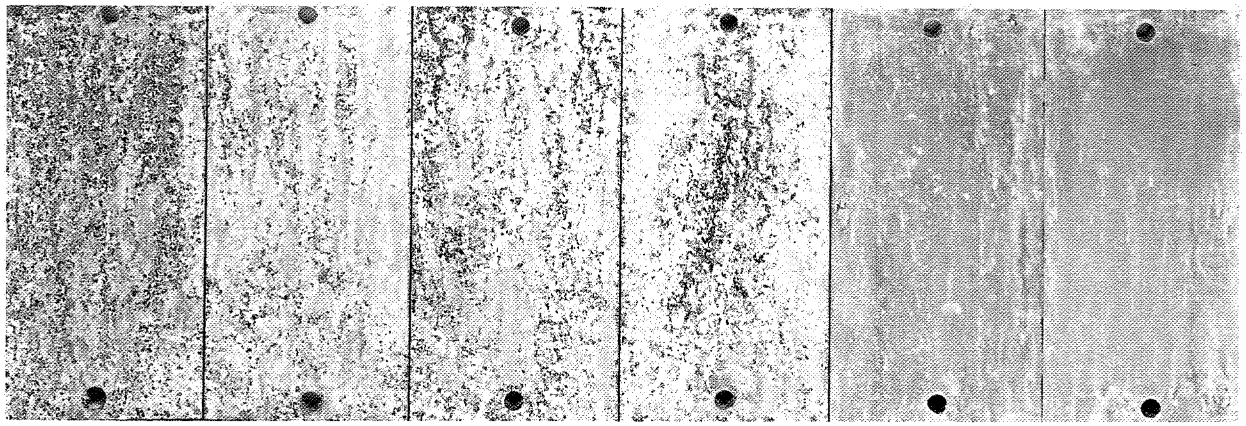


2219-T87
Mill Finish; H_2SO_4-CrO_3
1.25 oz/gal., pH 1.5

2219-T87
Mill Finish; H_2SO_4-CrO_3
1.25 oz/gal., pH 0.9

2219-T87
Mill Finish; H_2SO_4-CrO_3
6 oz/gal., pH 0.7

FIGURE 45 - 336 HOURS SALT SPRAY EXPOSURE



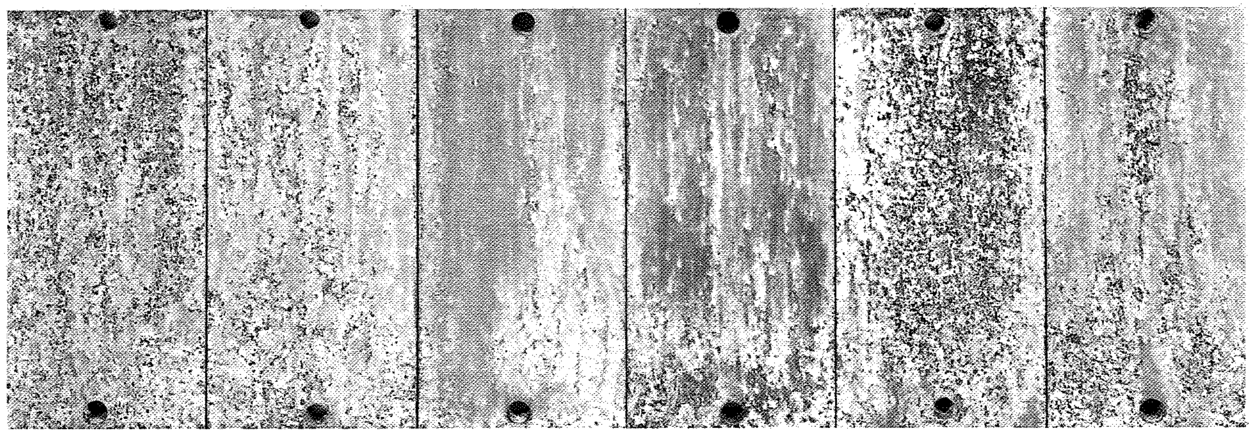
2219-T87
Chem Milled
1.25 oz/gal., pH 1.5

2219-T87
Mill Finish; H_2SO_4-CrO_3
1.25 oz/gal., pH 1.5

2219-T87
Machined
1.25 oz/gal., pH 1.5

FIGURE 46 - 336 HOURS SALT SPRAY EXPOSURE

PDG063CJ

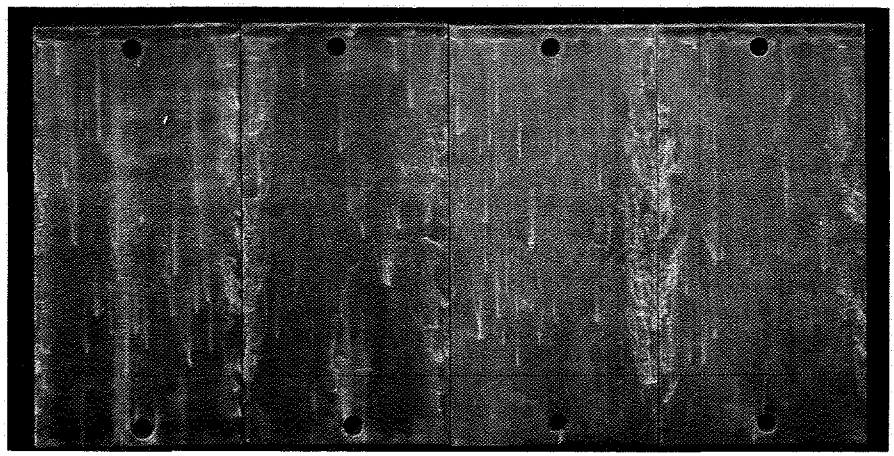


2219-T87
Chem Milled
1.25 oz/gal., pH 1.5

2219-T87
Chem Milled
1.25 oz/gal., pH 0.9

2219-T87
Chem Milled
6 oz/gal., pH 0.7

FIGURE 47 - 336 HOURS SALT SPRAY EXPOSURE



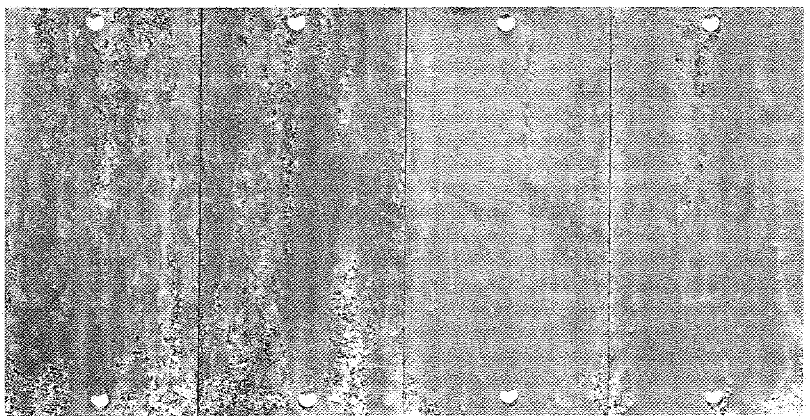
2219-T87
1.25 oz/gal. pH 0.9

2219-T87
1.25 oz/gal. pH 0.9
Dichromate Sealed

SALT SPRAY TEST NO. 3
168 HOURS EXPOSURE

FIGURE 48

PDG068CJ

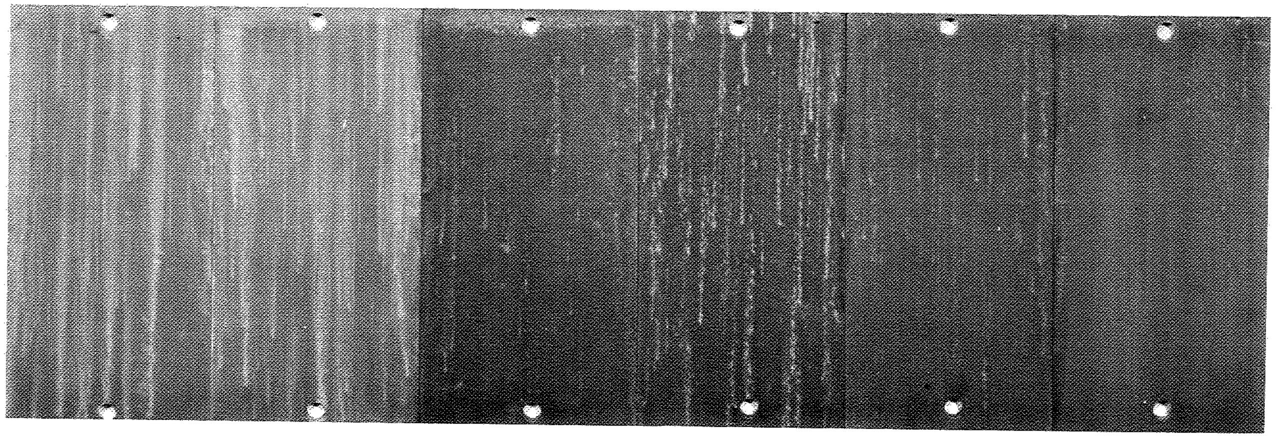


2219-T87
1.25 oz/gal,, pH 0.9

2219-T87
1.25 oz/gal., pH 0.9
Dichromate Sealed

FIGURE 49 - 336 HOURS SALT SPRAY
EXPOSURE

PDE092CJ



2219-T87
H_2SO_4-CrO_3 Etch
1.25 oz/gal., pH 1.5

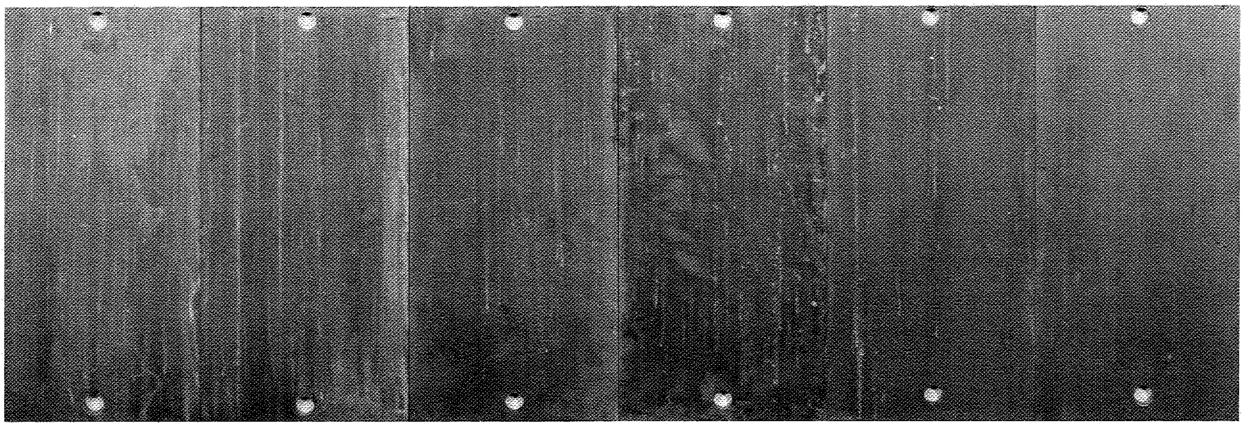
2219-T87
H_2SO_4-CrO_3 Etch
1.25 oz/gal., pH 0.9

2219-T87
H_2SO_4-CrO_3 Etch
6 oz/gal., pH 0.7

SALT SPRAY TEST NO. 6
168 HOURS EXPOSURE

FIGURE 50

PDE093CJ



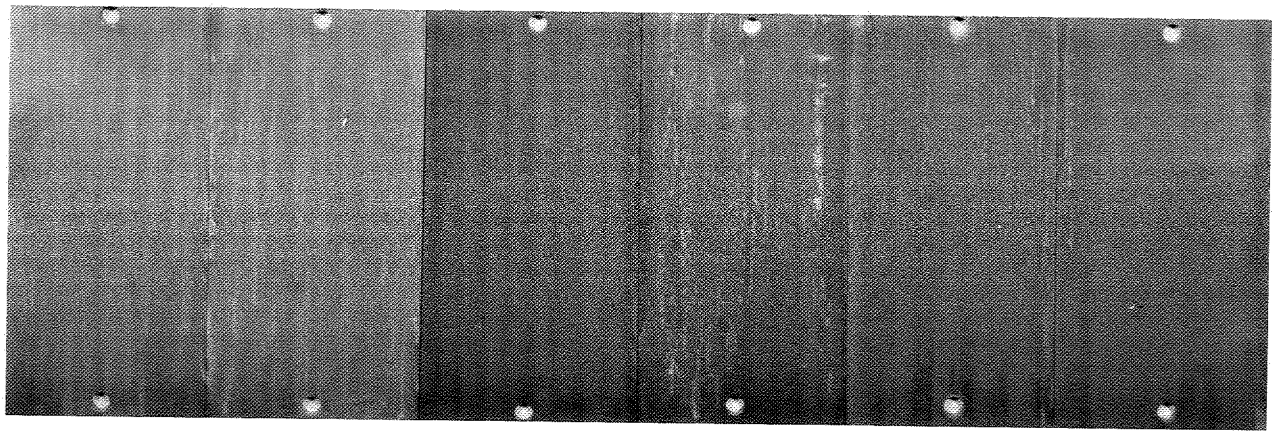
2219-T87
HNO_3-HF Etch
1.25 oz/gal., pH 1.5

2219-T87
HNO_3-HF Etch
1.25 oz/gal., pH 0.9

2219-T87
HNO_3-HF Etch
6 oz/gal., pH 0.7

SALT SPRAY TEST NO. 6
168 HOURS EXPOSURE

FIGURE 51



2219-T87
H_2SO_4-HNO_3 Etch
1.25 oz/gal., pH 1.5

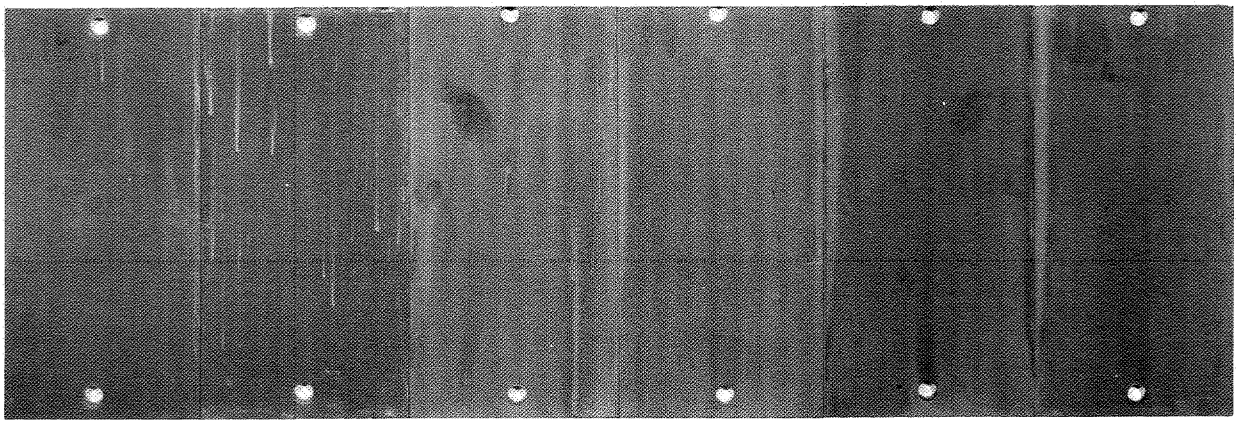
2219-T87
H_2SO_4-HNO_3 Etch
1.25 oz/gal., pH 0.9

2219-T87
H_2SO_4-HNO_3 Etch
6 oz/gal., pH 0.7

Salt Spray Test No. 6
168 Hours Exposure

Figure 52

PDE095CJ



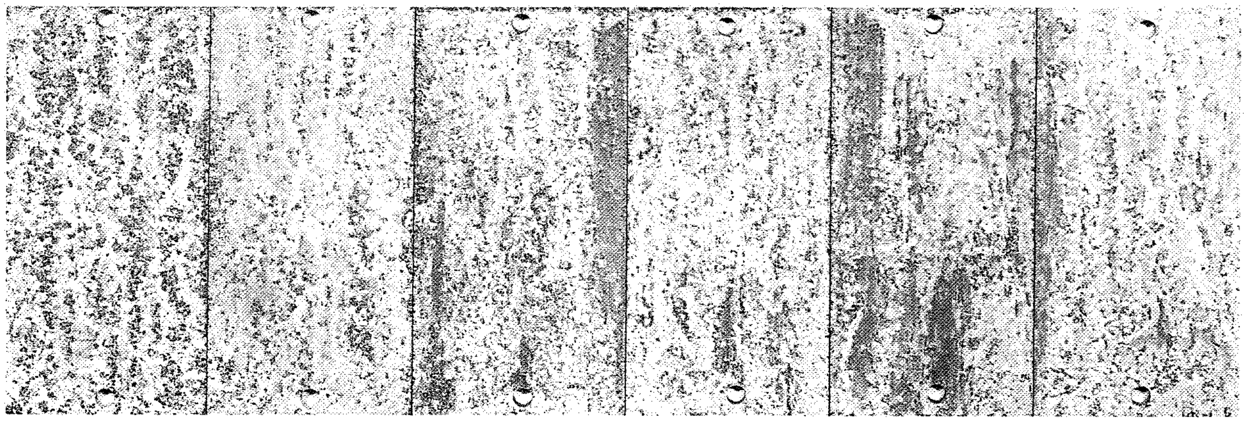
2219-T87
Scotch Brite
1.25 oz/gal., pH 1.5

2219-T87
Scotch Brite
1.25 oz/gal., pH 0.9

2219-T87
Scotch Brite
6 oz/gal., pH 0.7

SALT SPRAY TEST NO. 6
168 HOURS EXPOSURE

FIGURE 53

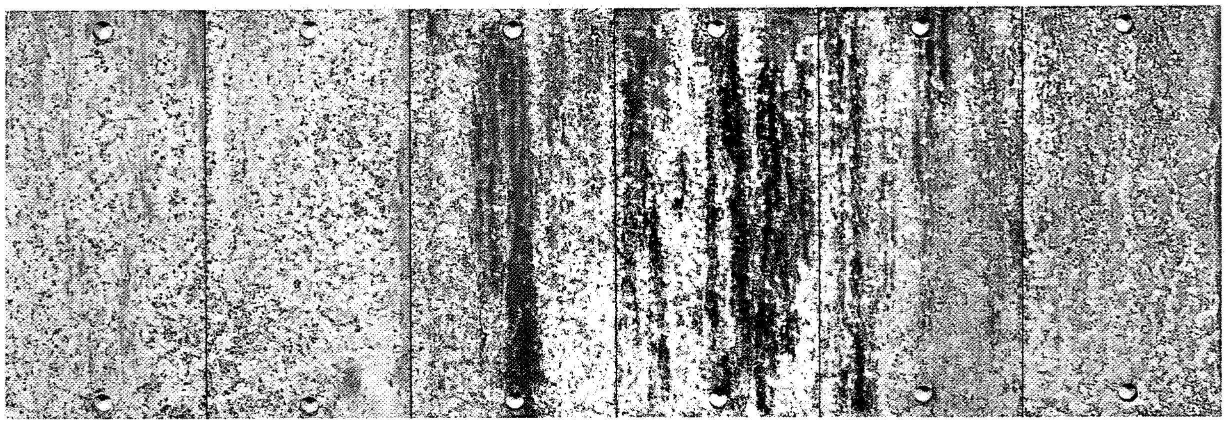


2219-T87
H_2SO_4-CrO_3
1.25 oz/gal., pH 1.5

2219-T87
H_2SO_4-CrO_3
1.25 oz/gal., pH 0.9

2219-T87
H_2SO_4-CrO_3
6 oz/gal., pH 0.7

FIGURE 54 - 336 HOURS SALT SPRAY EXPOSURE

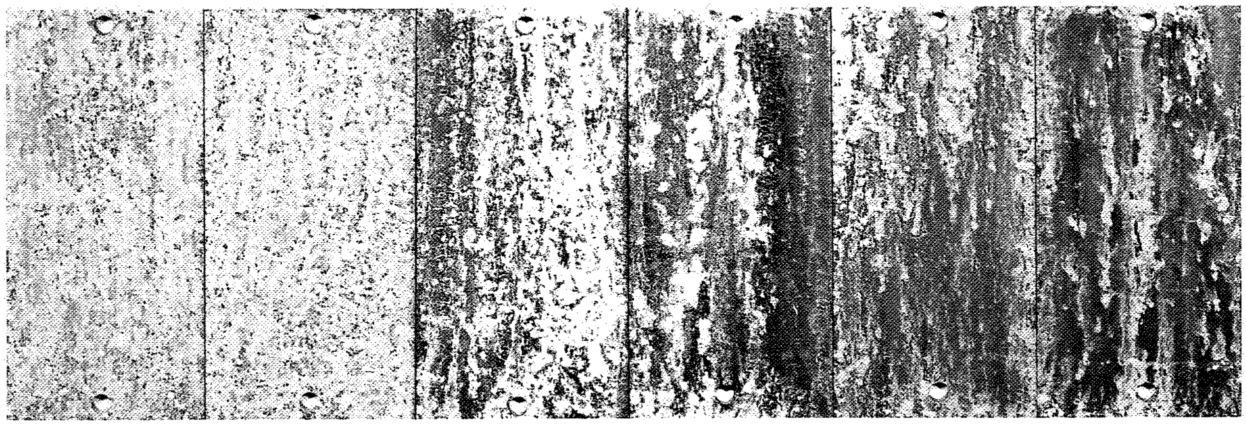


2219-T87
HNO_3-HF
1.25 oz/gal., pH 1.5

2219-T87
HNO_3-HF
1.25 oz/gal., pH 0.9

2219-T87
HNO_3-HF
6 oz/gal., pH 0.7

FIGURE 55 - 336 HOURS SALT SPRAY EXPOSURE

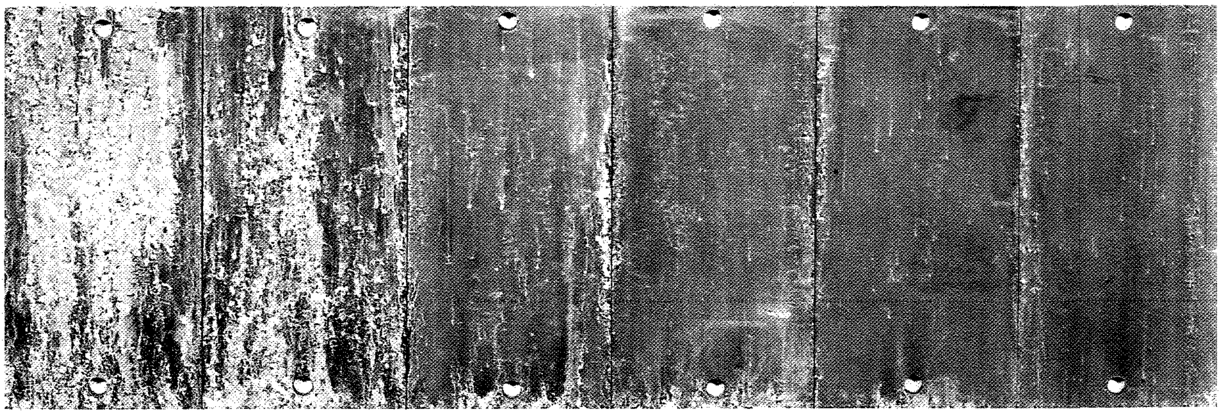


2219-T87
H_2SO_4-HNO_3
1.25 oz/gal., pH 1.5

2219-T87
H_2SO_4-HNO_3
1.25 oz/gal., pH 0.9

2219-T87
H_2SO_4-HNO_3
6 oz/gal., pH 0.7

FIGURE 56 - 336 HOURS SALT SPRAY EXPOSURE

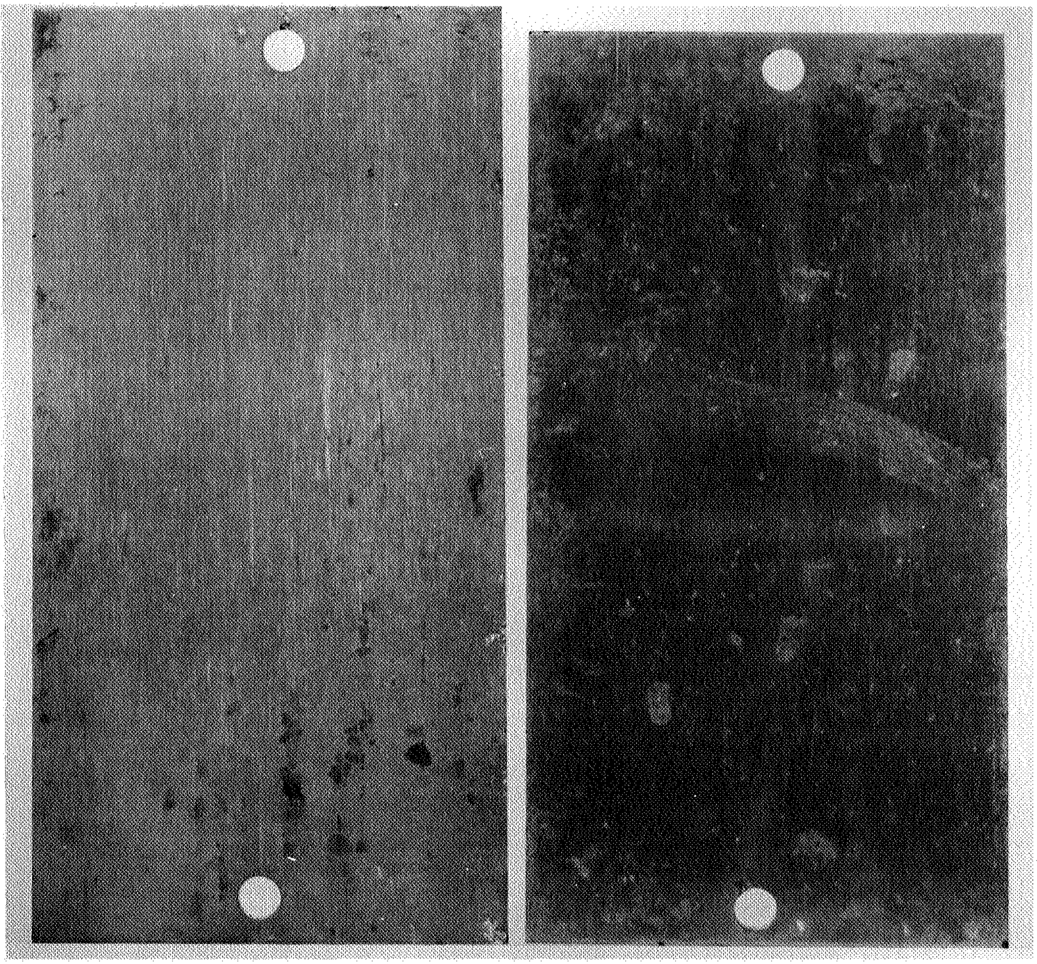


2219-T87
Scotch Brite
1.25 oz/gal., pH 1.5

2219-T87
Scotch Brite
1.25 oz/gal., pH 0.9

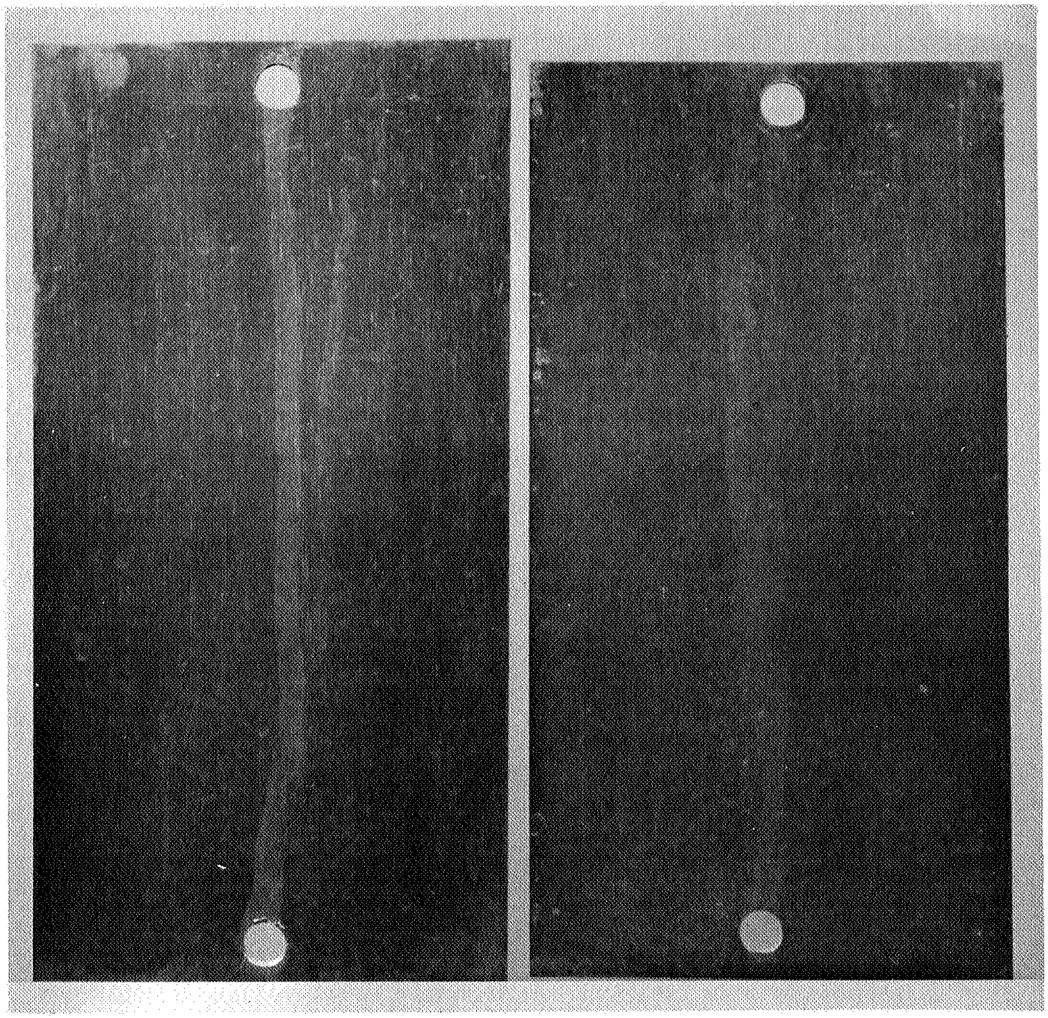
2219-T87
Scotch Brite
6 oz/gal., pH 0.7

FIGURE 57 - 336 HOURS SALT SPRAY EXPOSURE



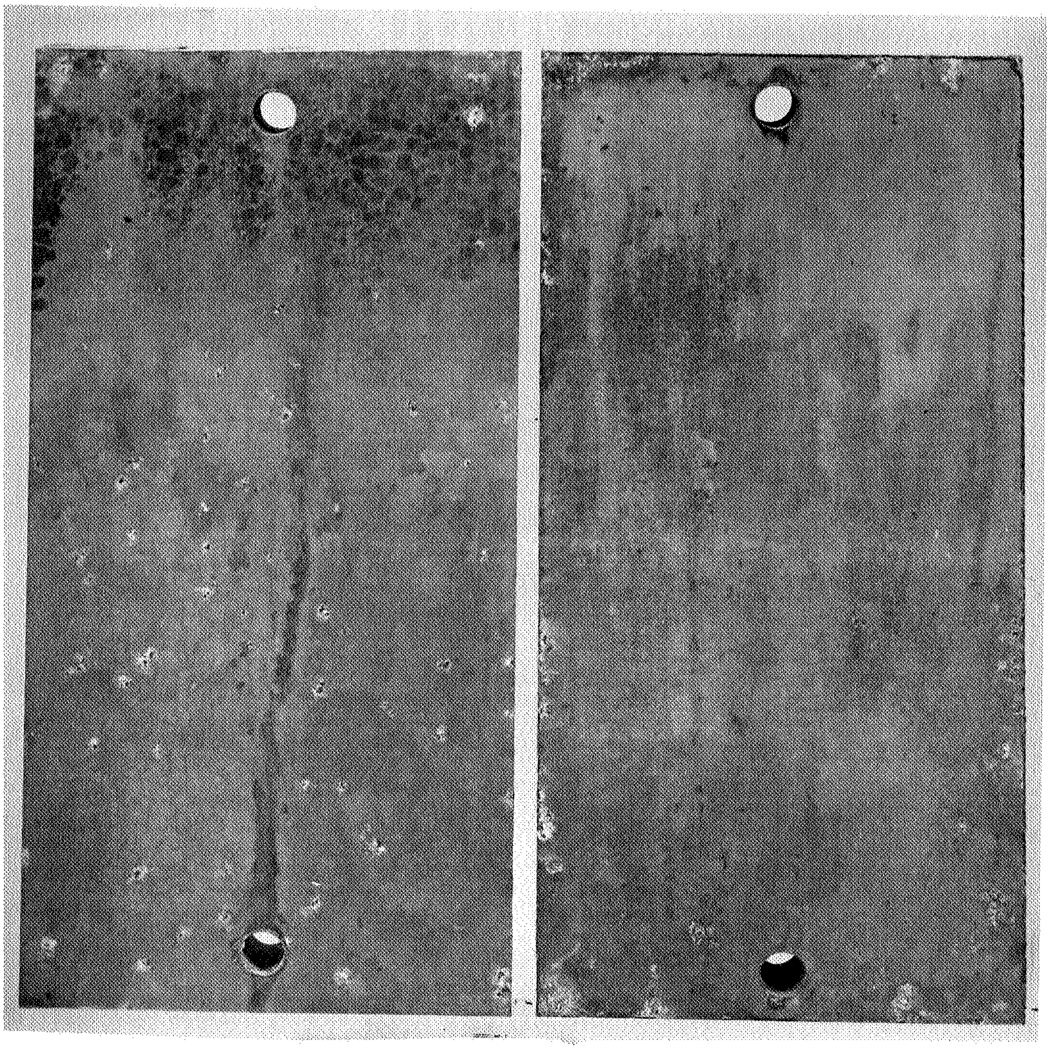
2014-T6 S-253528-4 1.25 oz/gal 7075-T6 S-252880-4 1.25 oz/gal

FIGURE 58 - 100% RH AT 125°F
ONE YEAR EXPOSURE



5052-H38 S-65644-4 1.25 oz/gal   6061-T6 S-283387-4 1.25 oz/gal

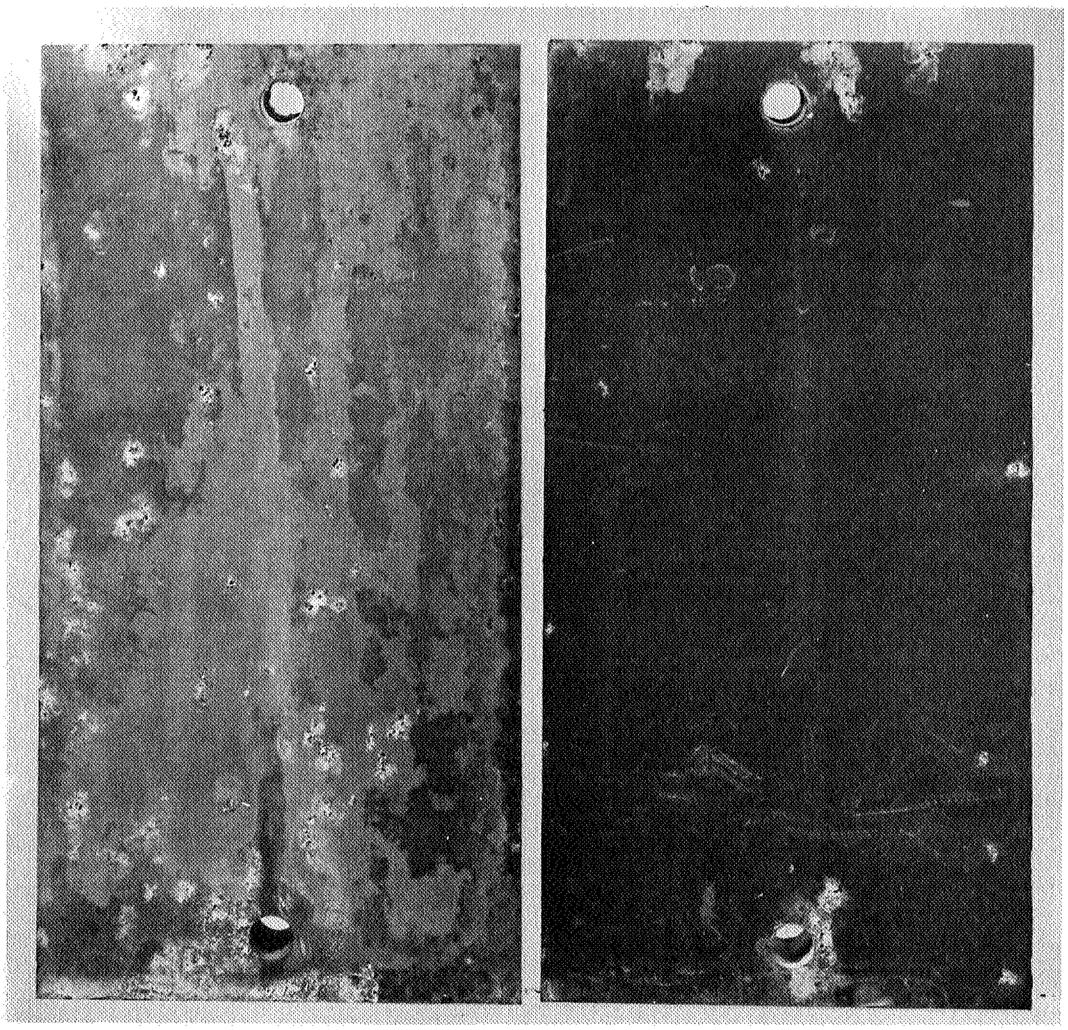
FIGURE 59 - 100% RH AT 125°F
ONE YEAR EXPOSURE



2219-T37 S-290081-3 1.25 oz/gal 2219-F S-290082-3 1.25 oz/gal

FIGURE 60 - 100% RH AT 125°F
ONE YEAR EXPOSURE

PEH082J

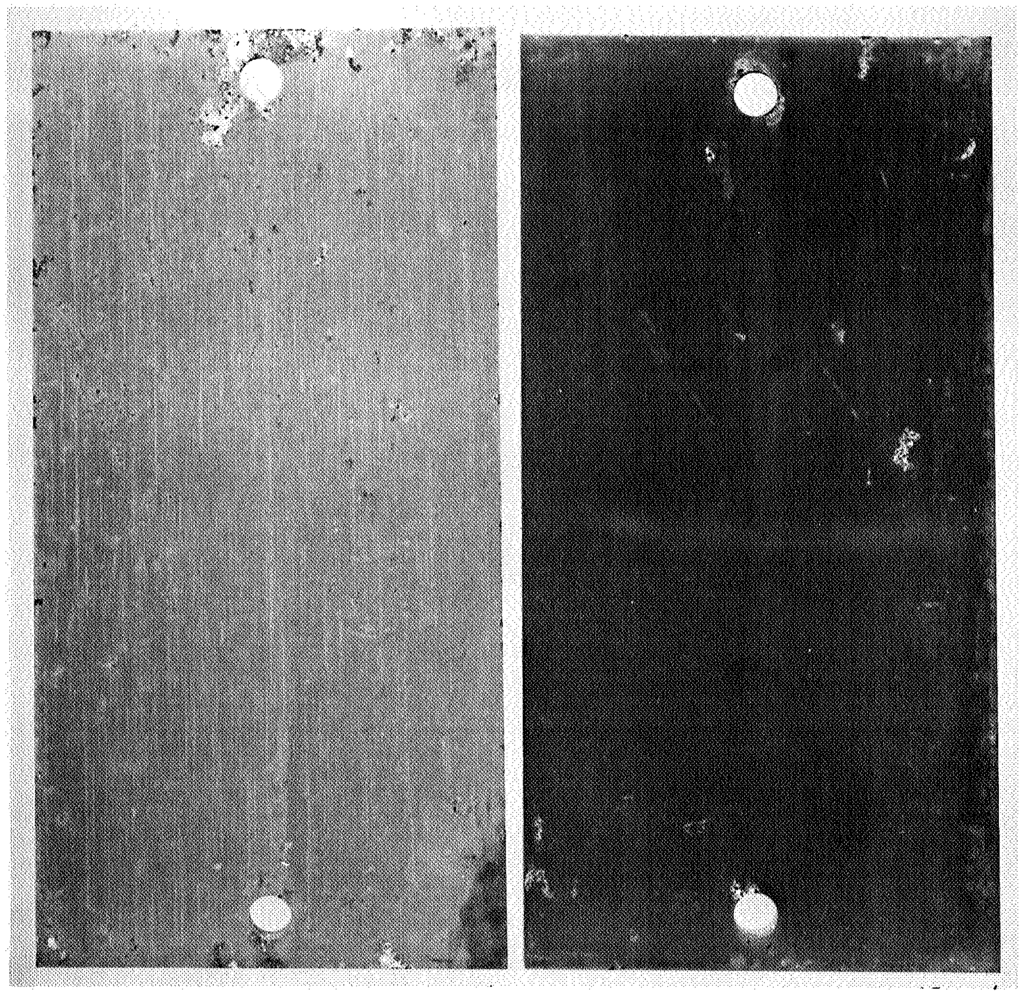


2219-T87 S-298548-B3 1.25 oz/gal 2219-T87 S-298548-C3 1.25 oz/gal

H_2SO_4-CrO_3 MACHINED

FIGURE 61 - 100% RH AT 125°F
ONE YEAR EXPOSURE

PEH083J



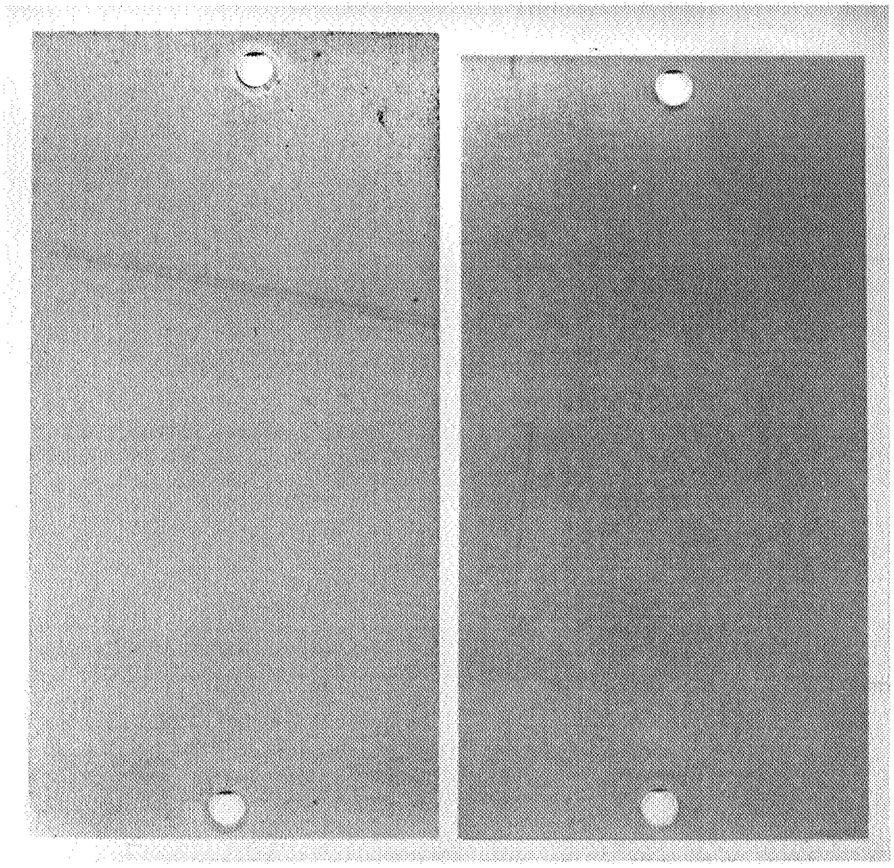
2219-T87 S-298552-A4 1.25 oz/gal

H_2SO_4-CrO_3

2219-T87 S-298552-D3 1.25 oz/gal

SCOTCH BRITE

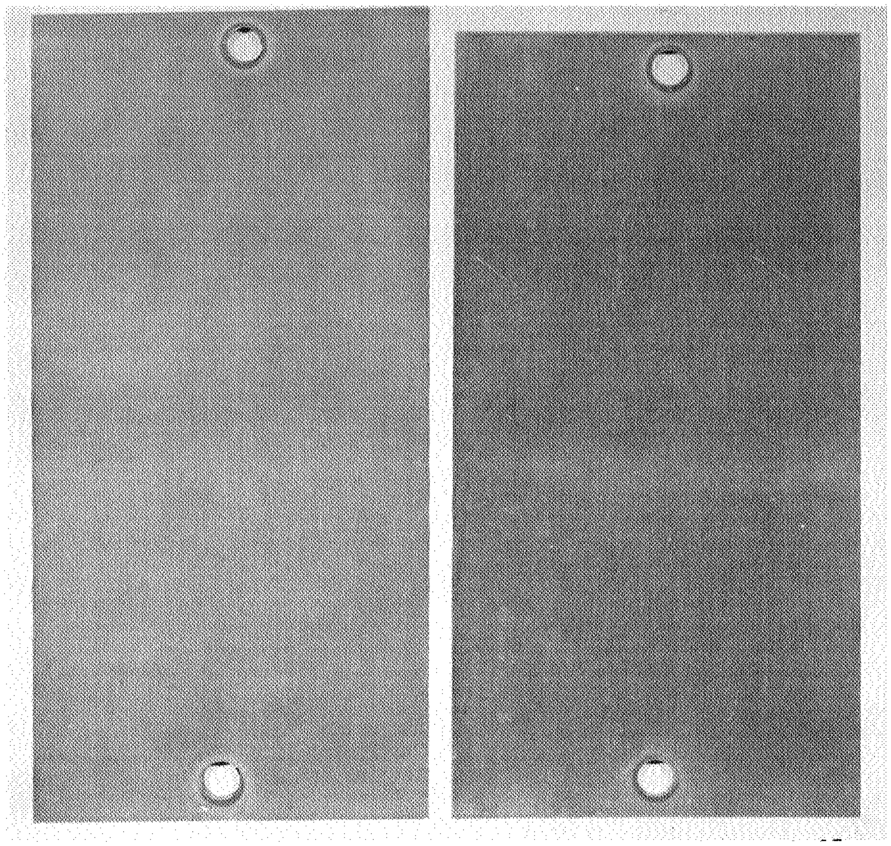
FIGURE 62 - 100% RH AT 125°F
ONE YEAR EXPOSURE



2014-T6 S-253528-7 1.25oz/gal 7075-T6 S-252880-7 1.25 oz/gal

FIGURE 63 - NEW KENSINGTON ATMOSPHERE

ONE YEAR EXPOSURE

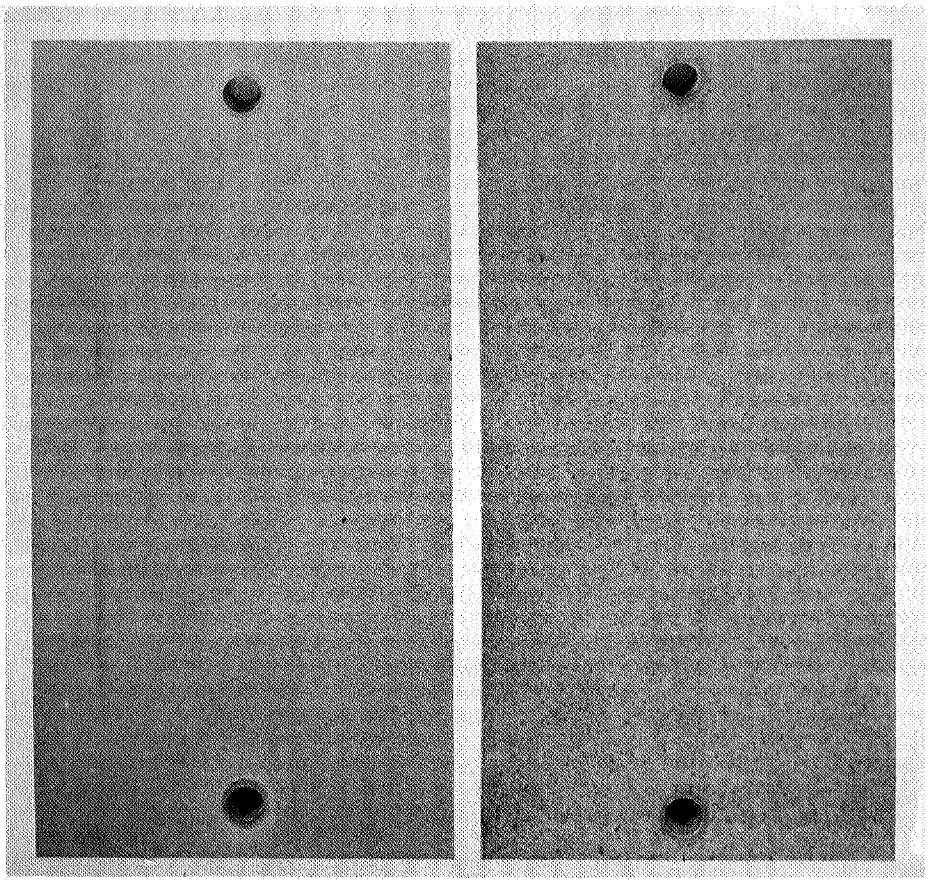


5052-H38 S-65644-7 1.25 oz/gal 6061-T6 S-283387-7 1.25 oz/gal

FIGURE 64 - NEW KENSINGTON ATMOSPHERE

ONE YEAR EXPOSURE

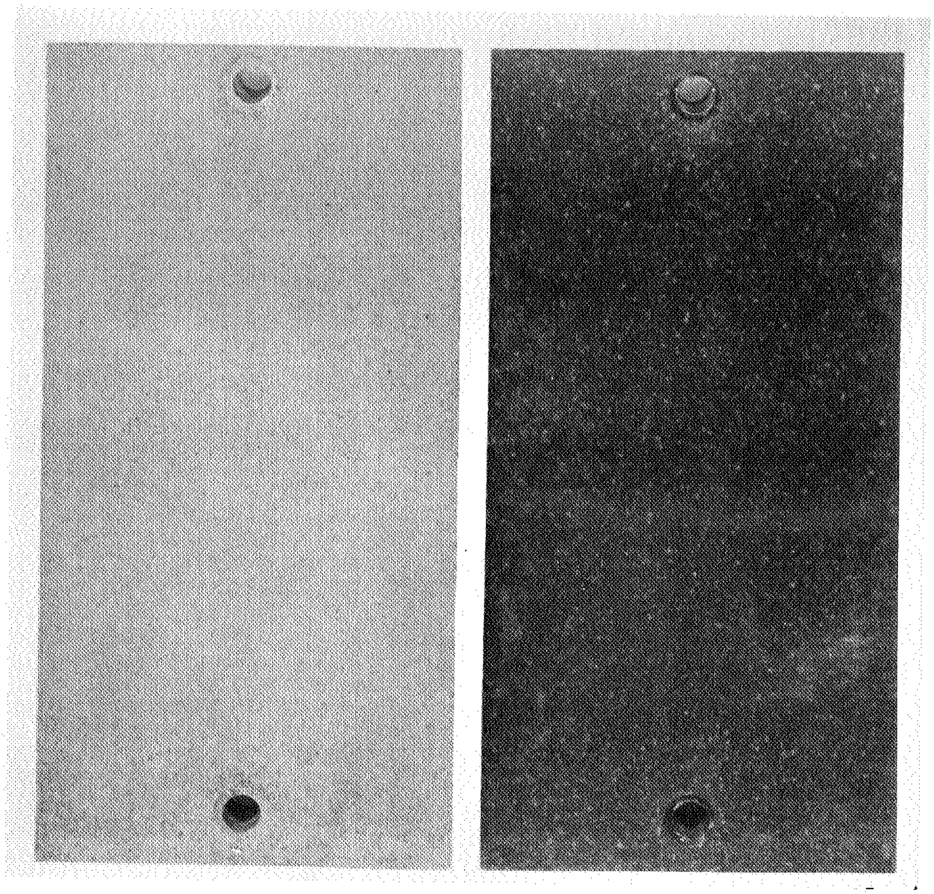
PEE201CJ



2219-T37 S-290081-5 1.25oz/gal 2219-F S-290082-5 1.25oz/gal

FIGURE 65 - NEW KENSINGTON ATMOSPHERE

ONE YEAR EXPOSURE

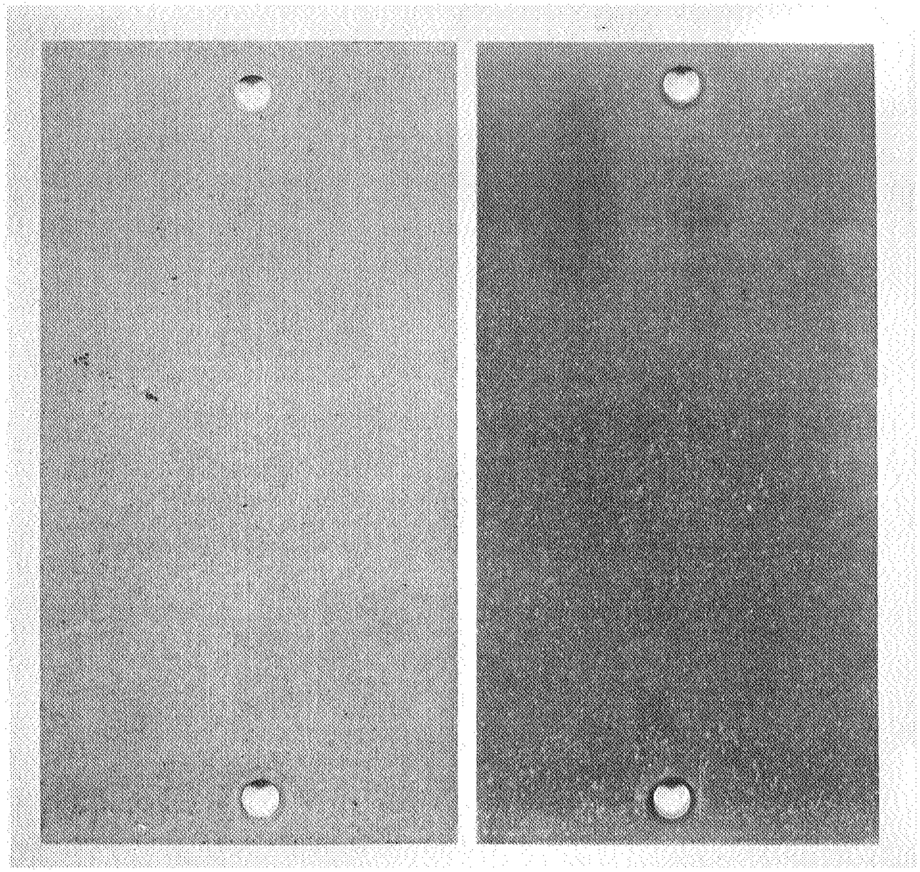


2219-T87 S-295548-B5 1.25 oz/gal 2219-T87 S-295548-C5 1.25oz/gal

H_2SO_4-CrO_3 MACHINED

FIGURE 66 - NEW KENSINGTON ATMOSPHERE

ONE YEAR EXPOSURE

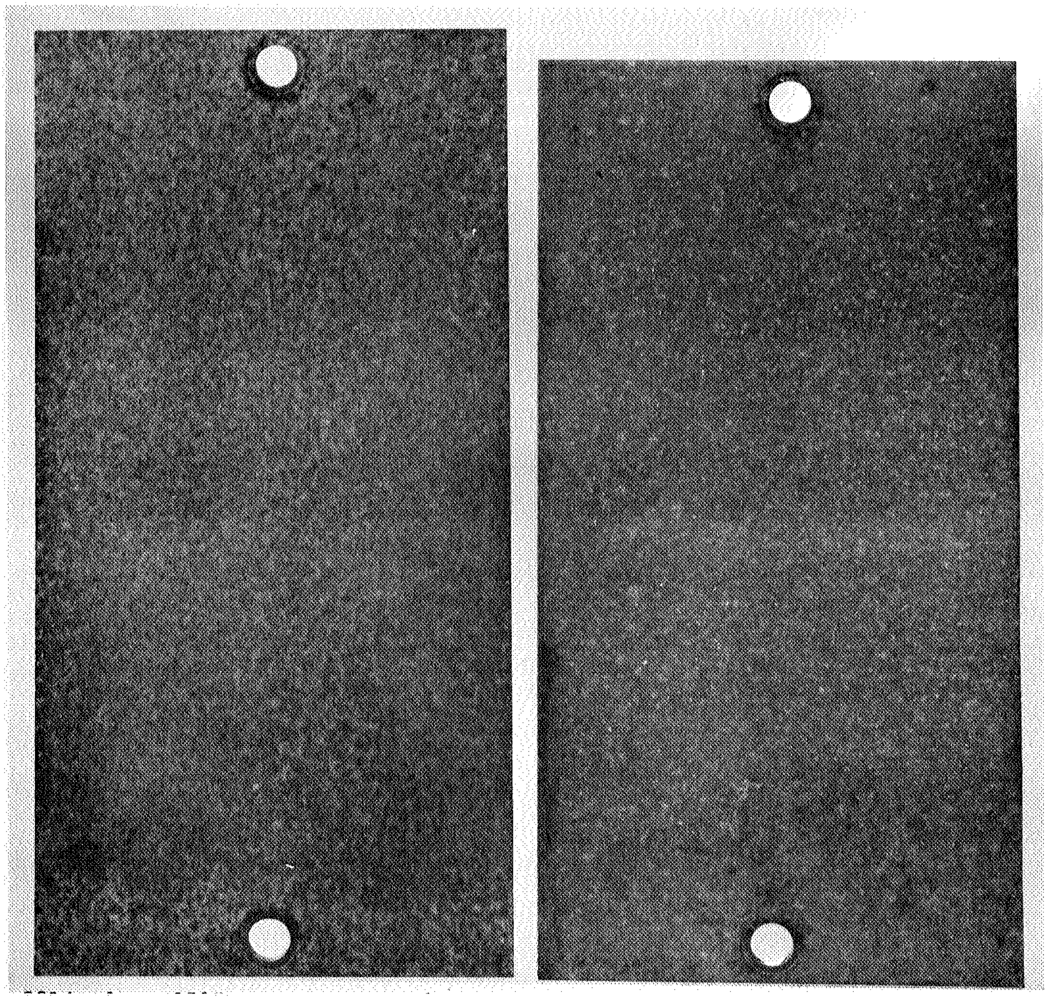


2219-T87 S-298552-A5 1.25 oz/gal 2219-T87 S-298552-D5 1.25 oz/gal

H_2So_4-CrO_3 SCOTCH BRITE

FIGURE 67 - NEW KENSINGTON ATMOSPHERE
ONE YEAR EXPOSURE

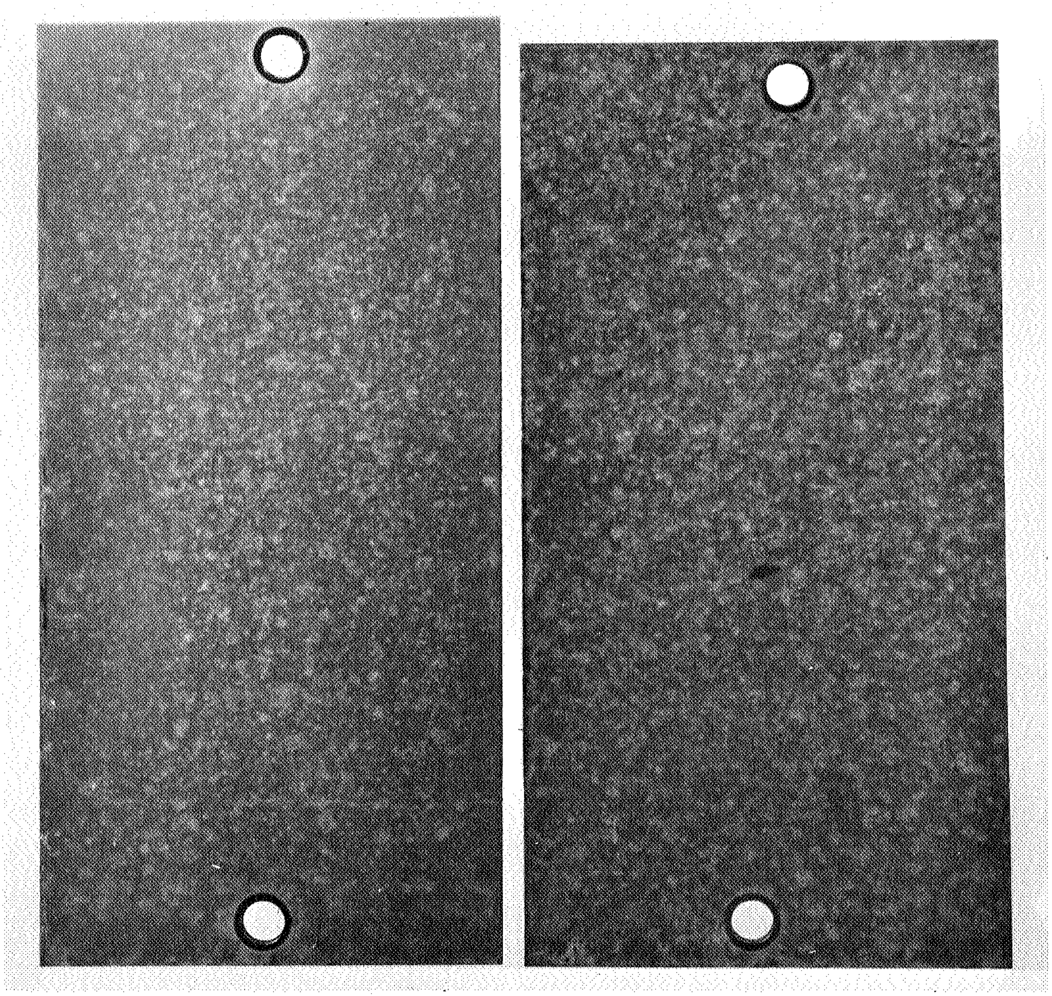
PEE204CJ



2014-T6 S-253528-10 1.25 oz/gal

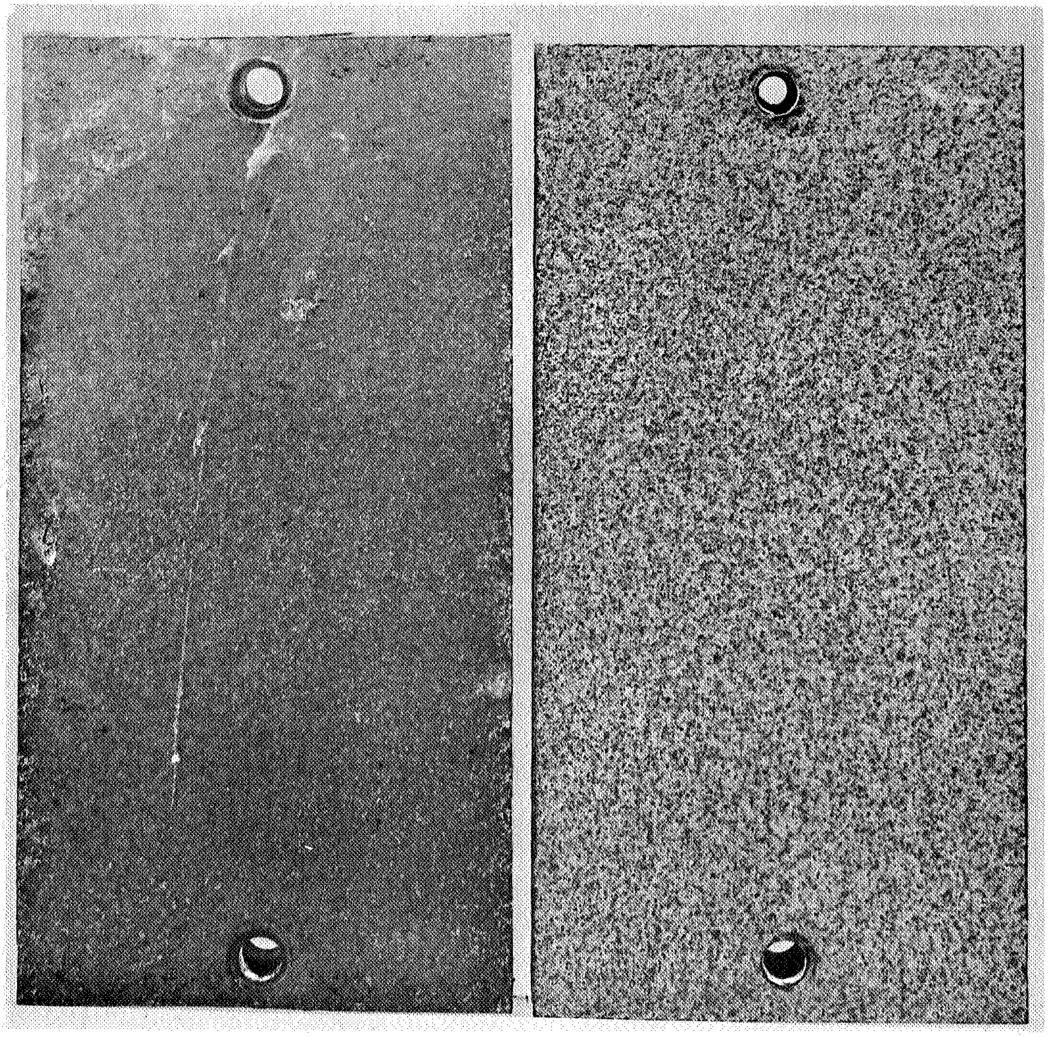
7075-T6 S-252880-10 1.25 oz/gal

FIGURE 68 - POINT JUDITH ATMOSPHERE
ONE YEAR EXPOSURE



5052-H38 S-65644-10 1.25 oz/gal 6061-T6 S-283387-10 1.25 oz/gal

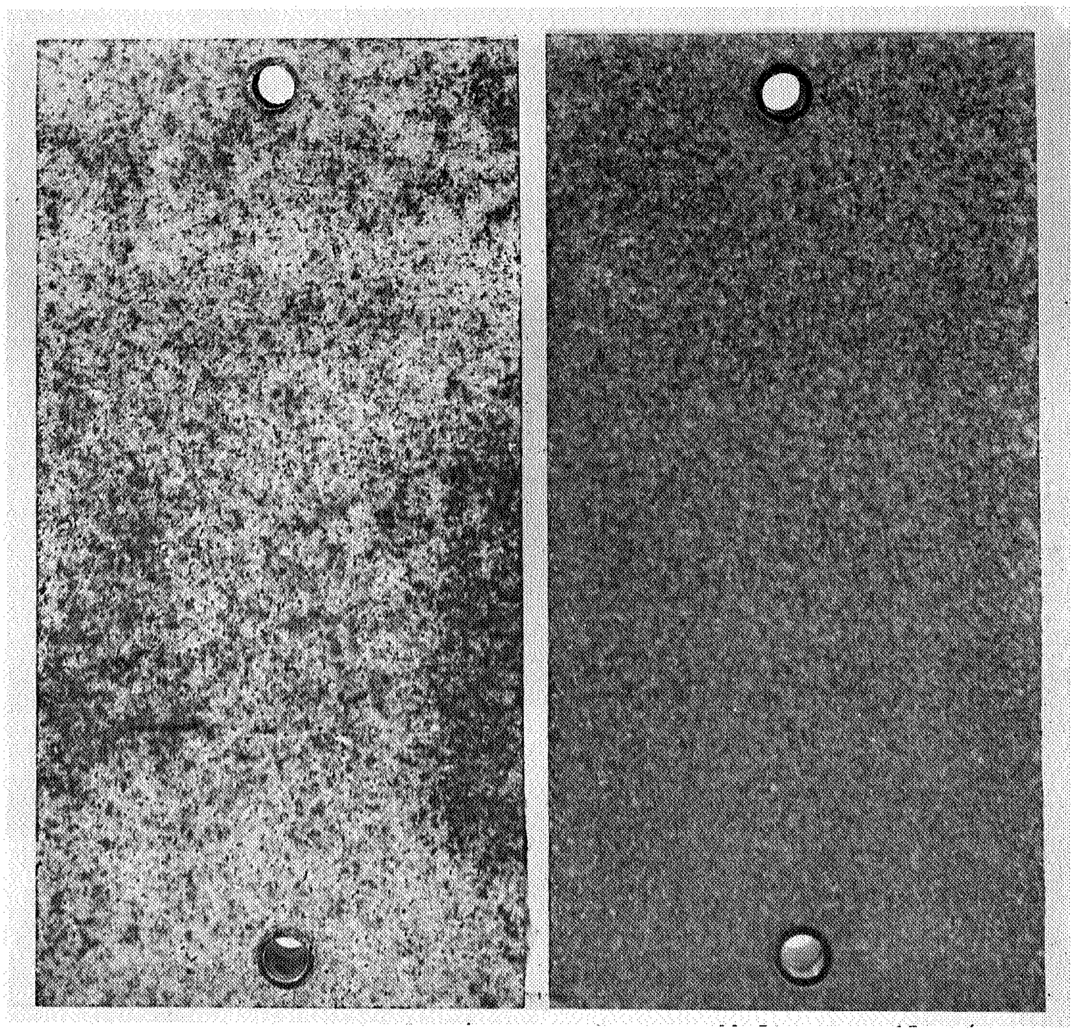
FIGURE 69 - POINT JUDITH ATMOSPHERE
ONE YEAR EXPOSURE



2219-T37 S-290081-8 1.25 oz/gal   2219-F S-390082-7 1.25 oz/gal

FIGURE 70 - POINT JUDITH ATMOSPHERE
ONE YEAR EXPOSURE

PEH092J



2219-T87 S-298548-B7 1.25 oz/gal

H_2SO_4-CrO_3

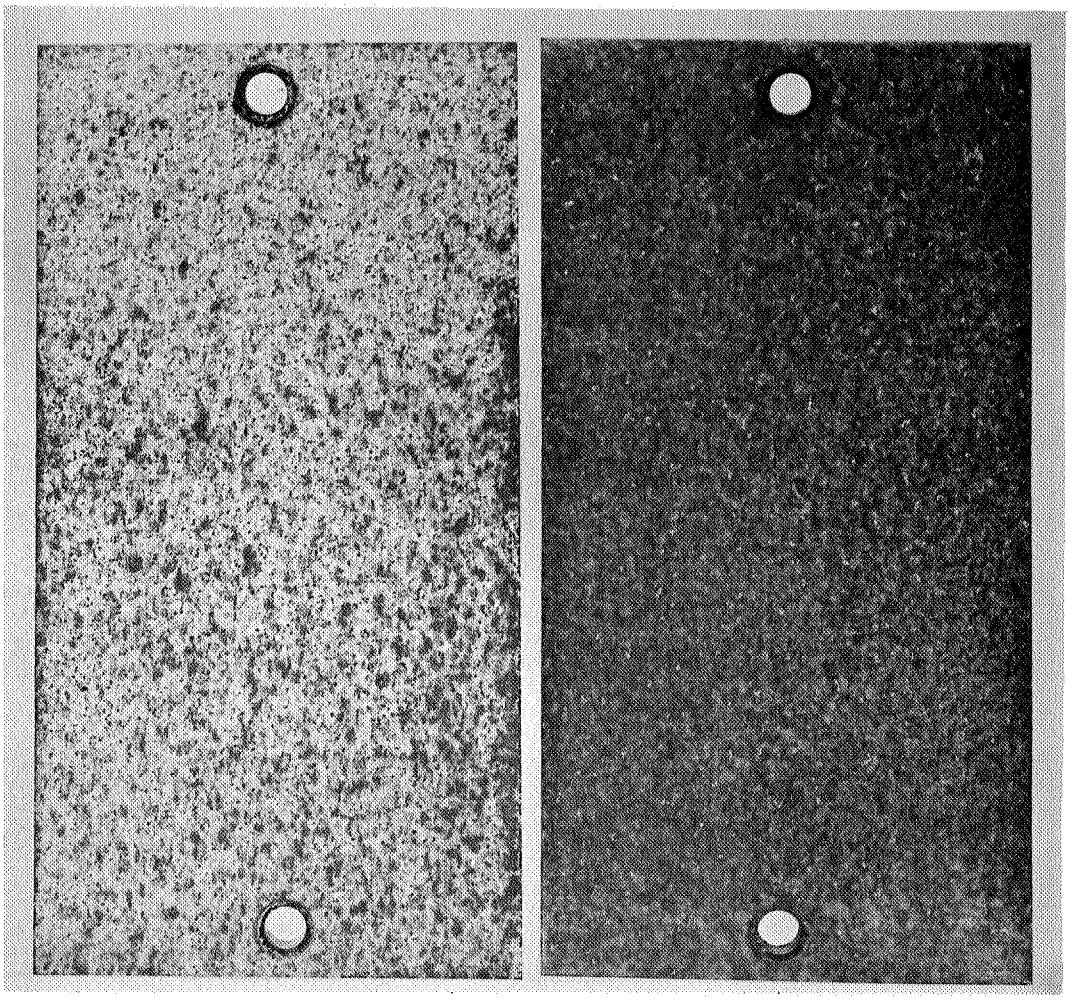
2219-T87 S-298548-C7 1.25 oz/gal

MACHINED

FIGURE 71 - POINT JUDITH ATMOSPHERE

ONE YEAR EXPOSURE

PEH093J



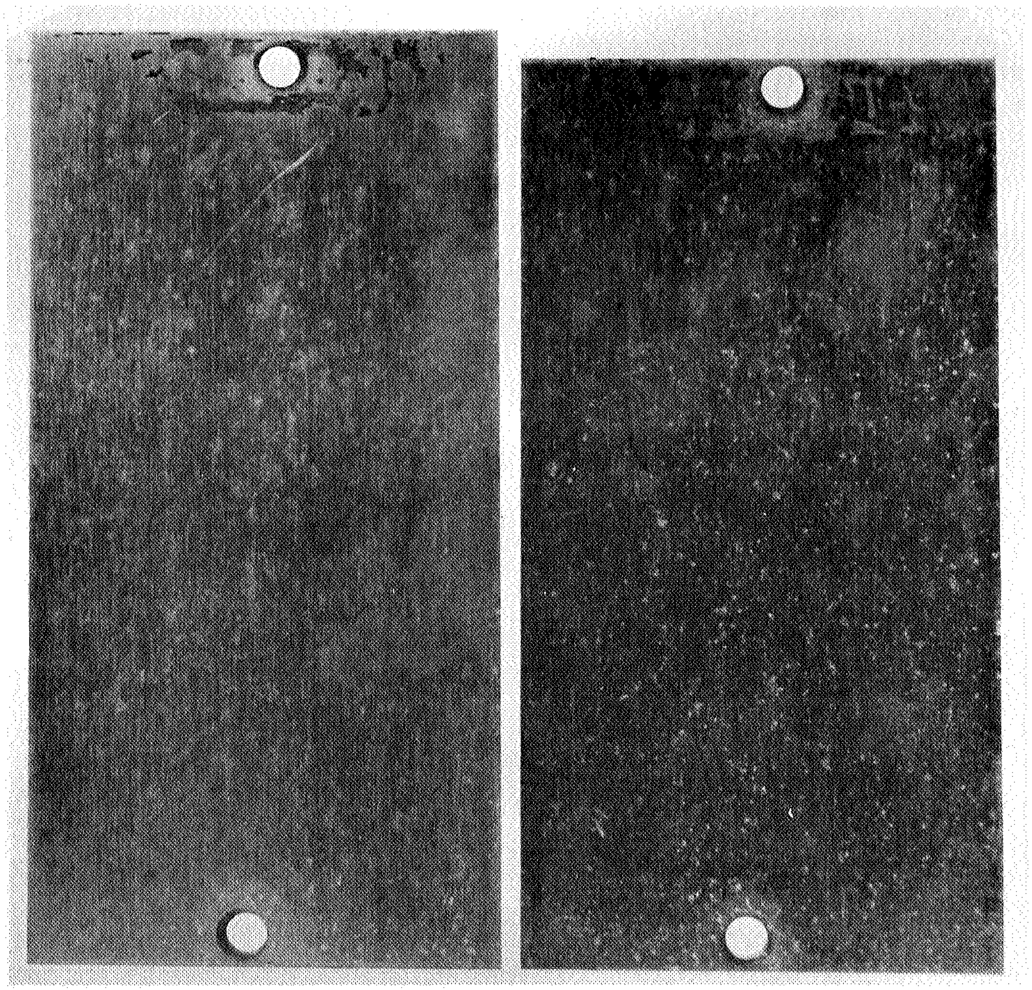
2219-T87 S-298552-A8 1.25 oz/gal 2219-T87 S-298552-D9 1.25 oz/gal

H_2SO_4-CrO_3 SCOTCH BRITE

FIGURE 72 - POINT JUDITH ATMOSPHERE

ONE YEAR EXPOSURE

PEH094J

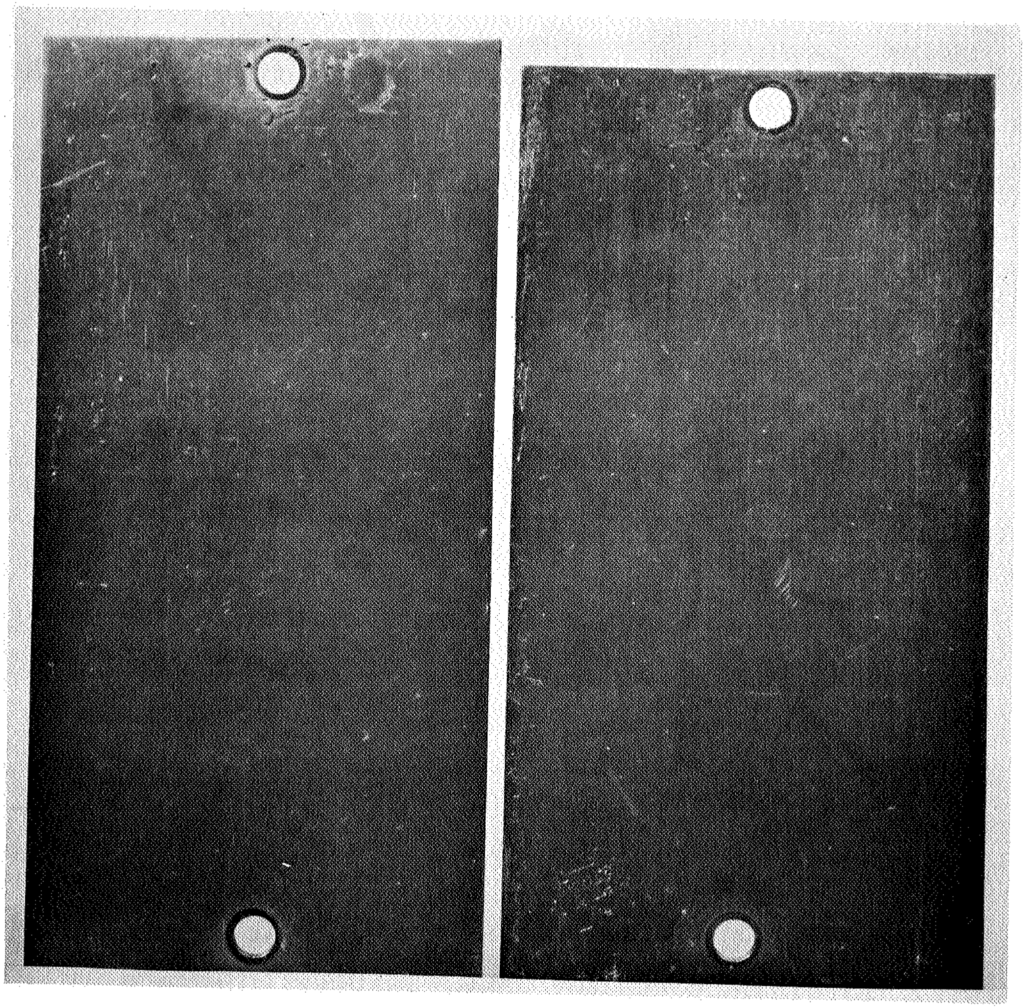


2014-T6 S-253528-13 1.25 oz/gal 7075-T6 S-252880-13 1.25 oz/gal.

FIGURE 73 - MIAMI ATMOSPHERE

ONE YEAR EXPOSURE

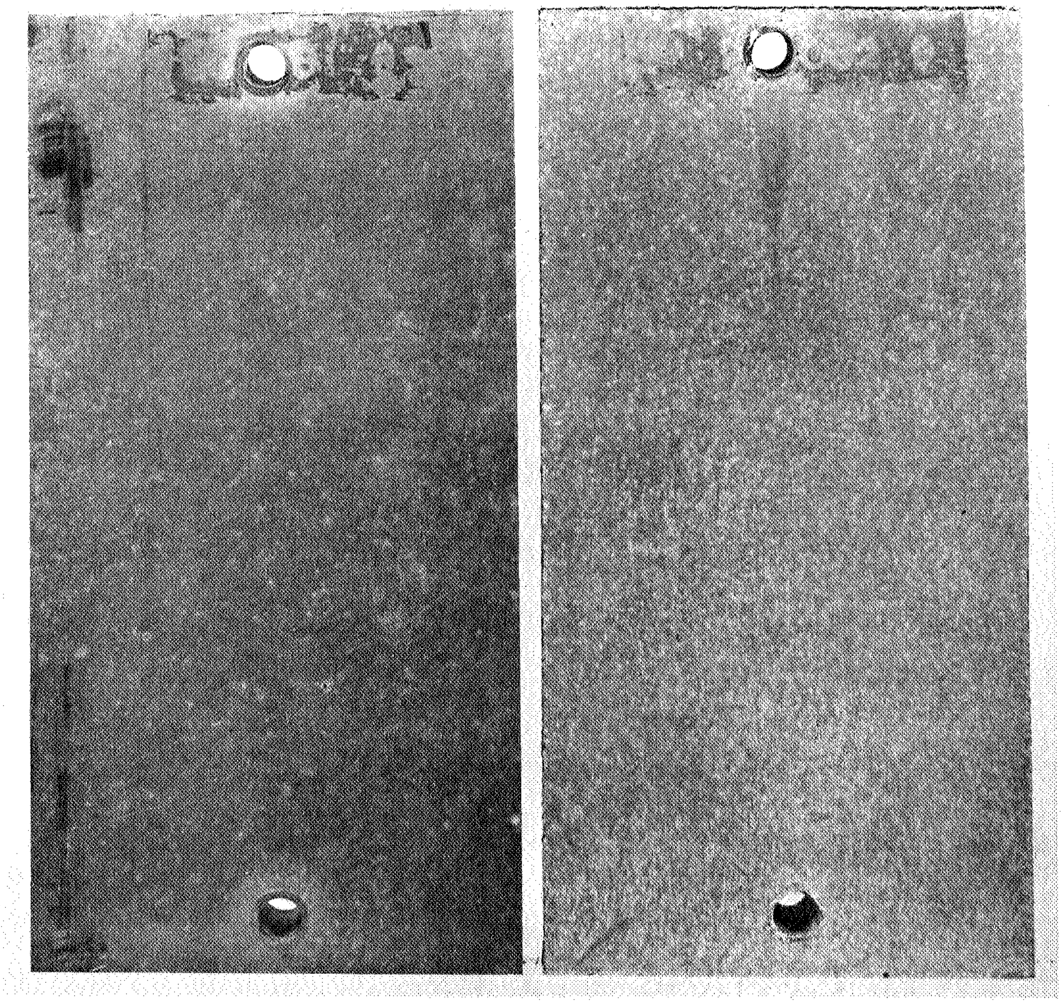
PEH085J



5052-H38 S-65644-13 1.25 oz/gal 6061-T6 S-283387-13 1.25 oz/gal

FIGURE 74 - MIAMI ATMOSPHERE

ONE YEAR EXPOSURE

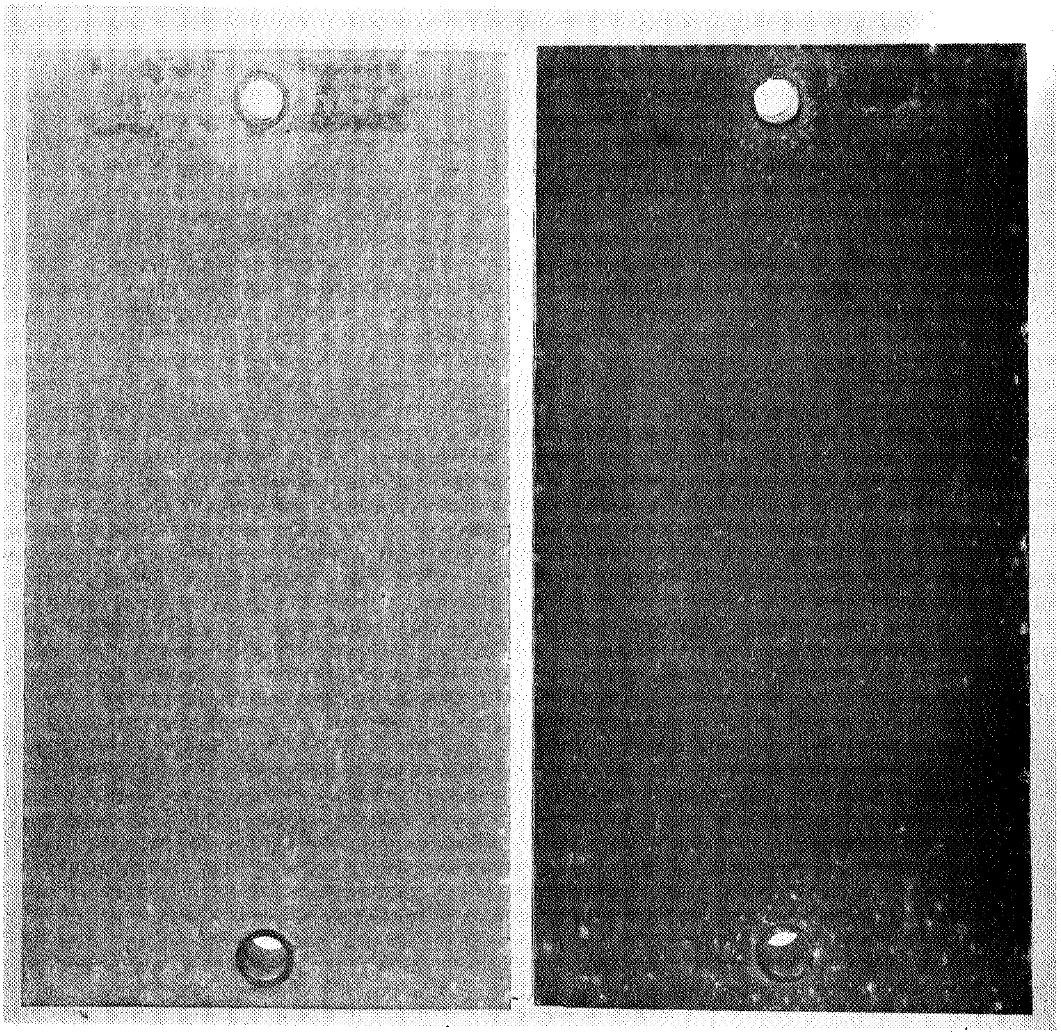


2219-T37 S-290081-9 1.25 oz/gal   2219-F S-290082-9 1.25 oz/gal

FIGURE 75 - MIAMI ATMOSPHERE

ONE YEAR EXPOSURE

PEH087J



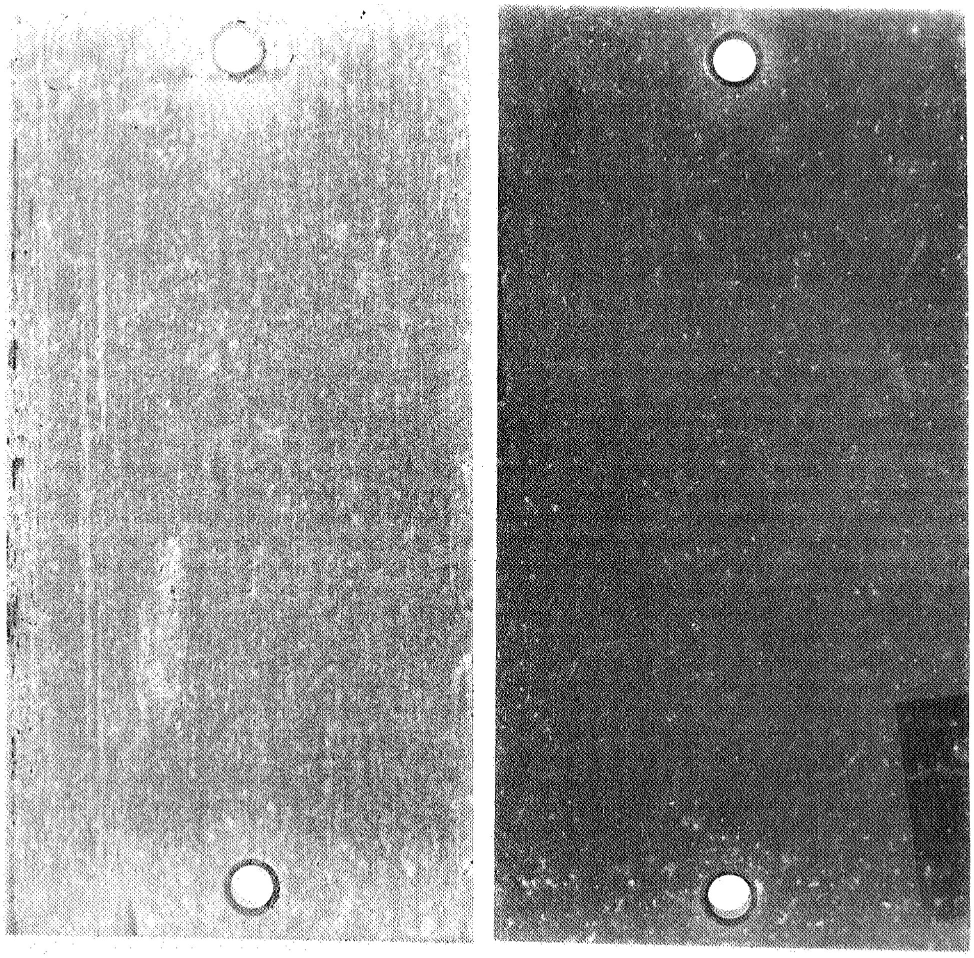
2219-T87 S-298548-B9 1.25 oz/gal 2219-T87 S-298548-C9 1.25 oz/gal

H_2SO_4-CrO_3 MACHINED

FIGURE 76 - MIAMI ATMOSPHERE

ONE YEAR EXPOSURE

PEH088J



2219-T87 S-298552-A11 1.25 oz/gal 2219-787 S-298552-D11 1.25 oz/gal

H_2SO_4-CrO_3 SCOTCH BRITE

FIGURE 77 - MIAMI ATMOSPHERE

ONE YEAR EXPOSURE