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It was the objective of this program to investigate the treatment of metal surfaces of aluminum, titanium and stainless steel alloys with organic polydentate agents instead of the conventional chromate-based conversion coatings in order to achieve improved paint adhesion and corrosion inhibition. Among the large number of chelating agents explored, the amino-phosphonate, amino-carboxylate and hydroxycarboxylate ligands with polymethylene backbones have shown promise. On the basis of reflectance infrared spectral examination, potentiostatic polarization tests and corrosion inhibition tests, it was found that although multimolecular layers of the ligands were deposited on the metal surfaces, they were held somewhat loosely. However, the paint adhesion characteristics of the chelate-treated metal substrates were comparable to those which had been treated with chromate-based conversion coatings (CHEMRITE). Satisfactory corrosion inhibition characteristics were shown by all the three alloy systems which had been pre-treated with the promising chelating agents followed by primer coating with epoxy primer. This study has indicated the potential of the chelation approach and the need for further research in this area.		

Security Classification

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Reflectance Infrared Spectra						
Aminocarboxylic acids						
Aminophosphonic acids						
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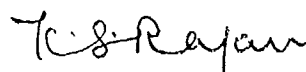
FOREWORD

This is Report No. IITRI-C6234-6 (Final Technical Report) of IITRI Project No. C6234, Contract No. N00019-71-C-0292 entitled, "Development of New Corrosion Inhibitors and Adhesion Promoters". This report describes the results of research work which was carried out under the above contract for the Naval Air Systems Command during the period January 4, 1971 through January 3, 1972.

Personnel who contributed to this project include Dr. K. S. Rajan, Frank H. Jarke, Robert Boes and Miss Audrone Valaitis.

Data are recorded in IITRI log books, C20368, C20370, C20429, C20624 and C20807.

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DEVELOPMENT OF CORROSION INHIBITORS AND ADHESION PROMOTERS

ABSTRACT

This program of research was conducted to investigate the chemical treatment of metal surfaces of aluminum, titanium and stainless steel alloys with organic polydentate chelating agents instead of chromate-based conversion coatings in order to achieve improved paint adhesion and corrosion inhibition. A number of chelating agents which have the combinations of metal-binding functionalities such as aminocarboxylate, aminophosphonate, hydroxycarboxylate, enolate and phenoxy groups with different molecular backbones were explored for their "surface chelation" tendencies for the three alloy systems. Visual and reflectance infrared spectral examinations of the chelate treated coupons followed by chemical testing of the reacting solutions of the chelating agents were carried out to detect surface chelation. Significant interactions by aminocarboxylic and aminophosphonic acids were indicated. On the basis of potentiostatic polarization tests and salt splash tests on unprimed coupons, it was observed that the surface-bound ligands were loosely held. Paint adhesion tests indicated that the adherence characteristics of a number of chelate-treated coupons compared favorably with those of chromate-treated coupons. The corrosion inhibition characteristics of primer coated coupons of all the three alloys which had been pre-treated with a number of the chelating agents were very satisfactory, although paint film blisters appeared on a number of the stainless steel and titanium test specimens. The results of this exploratory study have indicated the potential of this chelation approach and have demonstrated the need for further investigations of a few promising candidate chelating agents.

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DEVELOPMENT OF NEW CORROSION INHIBITORS AND ADHESION PROMOTORS

I. INTRODUCTION

Chemical conversion treatment of aluminum and other metal surfaces by acidic chromates (containing hexavalent Cr) and phosphates has been in practice for sometime. The chromate coating is brought about by immersing the oxide-free metal specimen in an acidic solution of (anionic) hexavalent chromium in the presence of one or more of the anions such as fluoride, sulfate, nitrate and ferricyanide. The resultant reaction which consists of a partial reduction of Cr(VI) to Cr(III) by the reacting metal surface, deposits a tightly adhering thin film of chromium chromate. The chemical conversion coating serves the dual role of (1) providing improved paint adhesion and (2) affording corrosion protection to the metal surface underneath the paint. However, mechanistic studies have indicated that the chromates are not entirely effective in controlling corrosion in crevices and at defect areas. Further it is felt that they might constitute a source of polluting the waters with chromium. The chromate ions do not migrate to the anodic defect area but rather prevent the spread of corrosion from cathodic under-film areas and depend on natural protective processes to repair the defect. It would appear that the most effective way to overcome the above disadvantages of chromate coatings is to look for compounds that could insure an adequate supply of ions at the anodic sites that are capable of chemically binding with the defect sites or of forming a protective film of insoluble compounds with the metal ions released at the anode. Further these compounds should afford improved paint adhesion with primers and top coats.

It is on the basis of the above considerations that

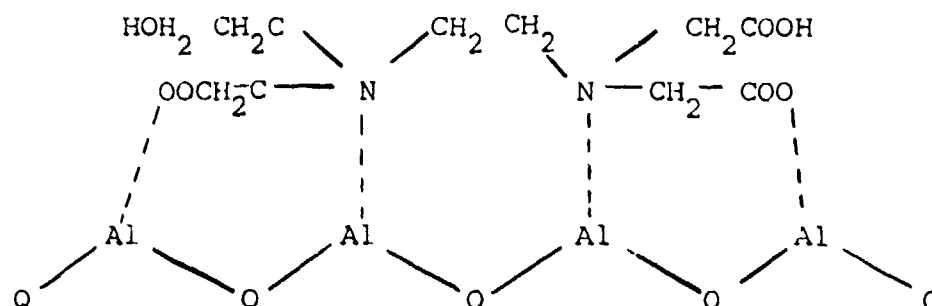
the current investigations were undertaken. The approach in the current project is based on the application of organic chelating agents to the chemical binding of metal surfaces. Polydentate chelating agents are those which contain two or more functional groups per molecule that can chemically bind metal ions. The metal-binding functional groups are covalently attached to the basic structural backbone of the chelating agents. The molecular backbone could consist of polymethylene groups, polymethylene amine groups and benzenoid groups. It is therefore reasonable to visualize that while the functional groups of the chelating agent chemically coordinate with the metal surface, the backbone structure is available for interacting with the paint vehicle (such as epoxy or polyurethane) and thus afford effective adherence.

It is generally known that metal surfaces consist of oxide layers of varying types and thicknesses. The surface of aluminum, for example, may be bound to hydroxyl groups, oxygen and to water molecules. Further, aluminum surface is reported to have Lewis acid sites. We can therefore visualize that a polydentate chelating agent can "chemically bind" the metal surface through the interactions of their functional groups (which act as Lewis bases). On thermodynamic grounds, it is reasonable to expect that a polydentate chelating agent can bind more strongly than a mono- or bidentate because of the formation of more than one "chelate ring" with metal substrates. The possible chemical binding of aluminum substrate by a typical polydentate chelating agent viz., N-hydroxyethylethylenediaminetriacetic acid (HEDTA) is illustrated by the following hypothetical structure (See Page 3).

By effectively chelating the metal surface with polydentate organic ligands, it is not only possible to shift the corrosion potentials to more noble values but also afford

improved paint adhesion because of the uncoordinated organic groups of the surface-bound chelating agents, e.g. the hydroxyethyl groups in the structure below. A number of polydentate organic compounds are known which provide a wide variety of metal-binding (coordinating) groups, solubility characteristics, thermodynamic stabilities and metal-ion selectives.

This program summarizes the results of the exploration of a number of such compounds for their surface-binding, paint adhesion and corrosion inhibition characteristics.



Metal substrate HEDTA "chelate"

II. EXPERIMENTAL INVESTIGATION

A. Selection of Candidate Compounds

Candidate chelating agents for the current investigation were selected from among the large number of known organic ligands on the basis of theoretical considerations. The important criteria for the selection of the compounds are: (1) they should have two or more metal-binding groups per mole of the ligand (ii) the donor groups should be in favorable steric arrangement in the ligand molecule so as to form stable "five or six-membered heterocyclic ring" structures with the metals, (iii) the basicities of the donor atoms should be such as to afford strong chelation with the surface sites of the metal substrates, (iv) the functional groups and/or the molecular backbone of the chelating agents should be such as to enhance paint adhesion (v) they should exhibit strong tendency to form insoluble inner complexes with the metal ions released at the anodic sites of corrosion reaction and (vi) limited solubility in aqueous and/or non-aqueous solvent media.

Organic compounds containing amino-, carboxylic, hydroxyl, phosphonic and carbonyl (diketone type) groups are known to coordinate (bind) polyvalent cations. A number of compounds are known in which one or more of the above groups are bound together covalently through polymethylene or polyaminopolymethylene molecular backbones. For this purpose multidentate ligands (i.e. that can bind two or more coordination sites of the metal atom) belonging to the classes of aminocarboxylic, hydroxycarboxylic, aminophosphonic, polycarboxylic and phosphonic acids should prove to be suitable candidates. A few of the candidate compounds that were thus selected for exploration are listed below for illustration:

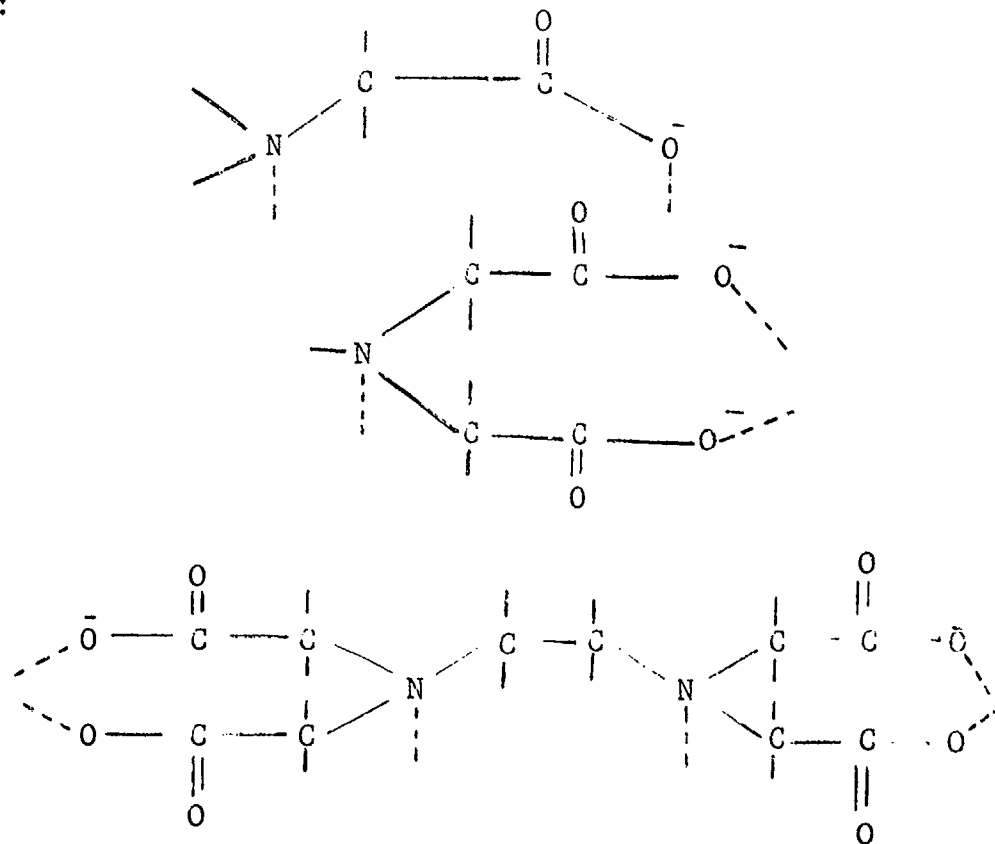
1. Aminopolycarboxylic Acids

- a. diethylenetriaminepenta-acetic acid, (DTPA;

CHELON-80)

- b. ethylenediaminetetra-acetic acid (EDTA)
- c. trans-1,2-diaminocyclohexanetetra-acetic acid (CDTA)
- d. nitrilotriacetic acid (NTA)
- e. iminodiacetic acid (IMDA)
- f. pyridine-2,6-dicarboxylic acid (DPA)
- g. glycine, alanine, and glutamic acid

The characteristic atomic grouping of these classes of compounds is illustrated by the following structural backbones:

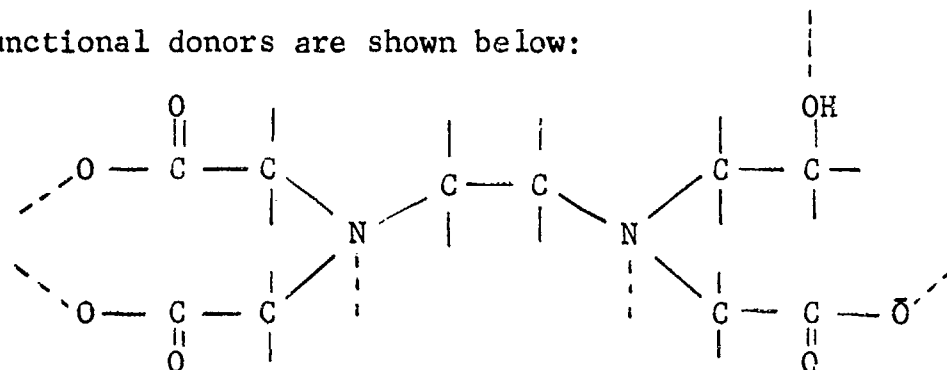


2. Hydroxyaminopolycarboxylic Acids

- a. N-hydroxyethyliminodiacetic acid, (HIMDA)
- b. N-hydroxyethylethylenediamine, N,N',N'-tri-acetic acid (HEDTA; CHELON-120)
- c. N,N-dihydroxyethylglycine (HXG; CHELON-DHG)

Structural illustrations of the atomic grouping and

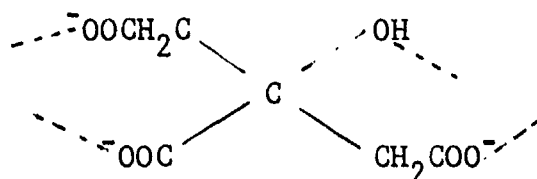
the functional donors are shown below:



3. Hydroxycarboxylic acids

- a. citric acid
- b. malic acid
- c. tartaric acid
- d. lactic acid
- e. mandelic acid
- f. salicylic acid

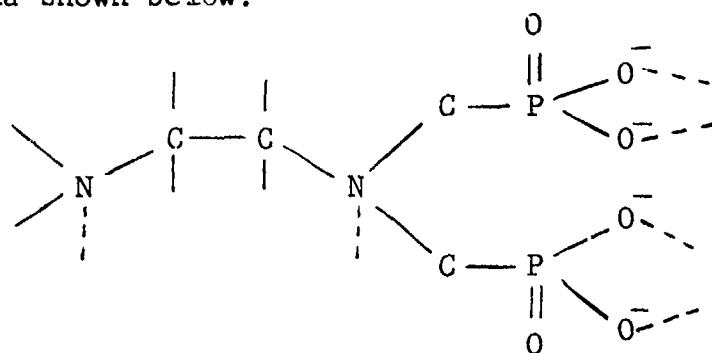
A typical hydroxycarboxylic acid, citric acid, is illustrated below:



4. Aminophosphonates

- a. aminotris(methylenephosphonic acid (DEQUEST-2000)
- b. penta-sodium salt of DEQUEST-2000 (DEQUEST-2006)
- c. ethylenediaminetetramethylenephosphonic acid (DEQUEST-2041)
- d. potassium salt of DEQUEST-2041 (DEQUEST-2044)
- e. potassium salt of hexamethylenediaminetetraphosphonic acid (DEQUEST-2054)
- f. ethanolaminedimethylenephosphonic acid
- g. diethyl-N,N-bis(2-hydroxyethyl)aminoethylphosphonate

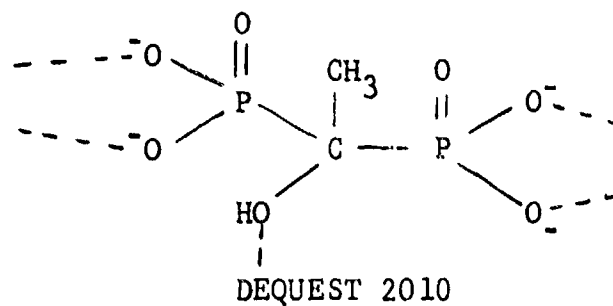
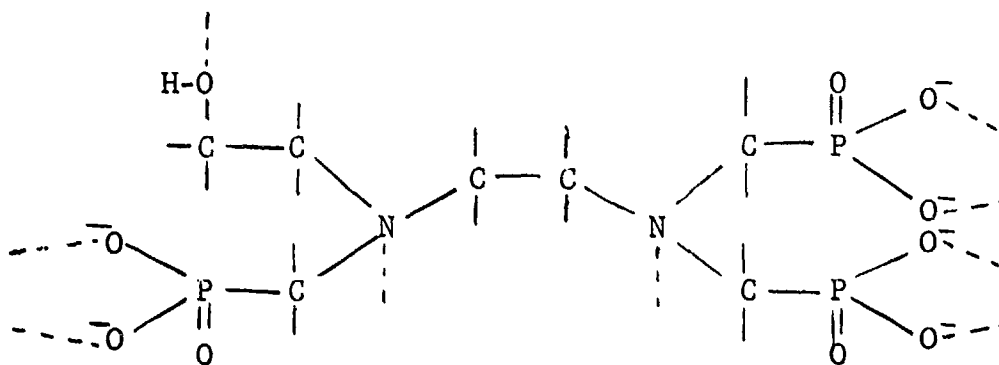
The atomic groupings of the molecular backbone and the metal-binding donors are illustrated by the structural formula shown below:



5. Phosphonic Acid

- a. 1-hydroxyethylidene-1,1-diphosphonic acid (DEQUEST-2010)
- b. diphenylphenylphosphonate (DPP)
- c. bis- β -chloroethylvinylphosphonate (Pyrol-Bis-Beta).

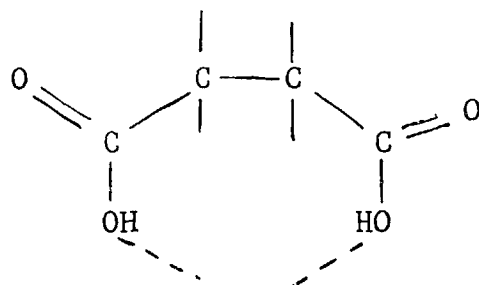
Compounds with hydroxyl groups are illustrated below:



6. Polycarboxylic Acids

- a. tricarballic acid
- b. succinic acid
- c. maleic acid
- d. malonic acid

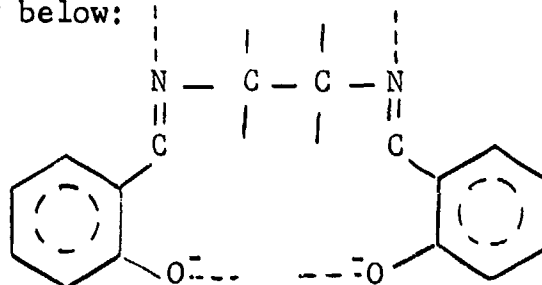
A typical dicarboxylic acid is structurally illustrated below:



7. Others

- a. acetylacetone
- b. pyrocatechol
- c. 8-hydroxyquinoline
- d. bis-(salicylaldehyde)ethylenediimine
- e. salicylhydroxamic acid

The atomic grouping and the four metal-binding groups of the multi-dentate ligand (d) above is illustrated structurally below:



B. Preparation of Metal Specimens

Aluminum alloys 7075-T6 and 2024-T3 were used in this research. The test specimens consisted of 1" x 2" x 1/16" pieces of the two alloys.

Test specimens of titanium consisted of the alloy Ti-6Al-4V, sizes 1" x 2" x 3/8" and 1" x 2" x 1/16".

In the case of stainless steel, samples of alloy #302 1" x 2" x 1/16" were used.

All the test specimens were first cleaned with toluene to remove all surface grease and other impurities and allowed to dry. They were then cleaned in (alkaline) OAKITE solution at 165-180°F for four minutes and rinsed free of the chemical in running distilled water. The specimens were then treated with dioxidizer solution (ARP 170) in order to remove the more porous upper layer of aluminum oxide and to leave available the more compact inner layer for binding with the chelating agent.

During the course of the investigations, it was felt desirable to adopt an acid-cleaning procedure (instead of the alkaline OAKITE cleaning) for the titanium and stainless steel samples. According to this procedure, the test coupons were first degreased with methyl ethyl ketone and dried. Next, they were washed with saturated ALCONOX solution and rinsed in water. The samples were then treated with a solution containing 25% nitric acid, 5% hydrofluoric acid and 70% water for ten minutes. This was followed by rinsing them in water and drying them in warm air (oven).

C. Treatment of Test Coupons With Chelating Agents

The treatment method consisted of equilibrating the test coupons with solutions of the chelating agent for a maximum of 24 hours. Five percent solutions of the candidate chelating agents in aqueous media were used and the impregnation experiments were run at ambient temperature. In each case, the solution was kept vigorously stirred during the course of the equilibration of the test coupon. At the end of the treatment, the specimens were rinsed and allowed to air-dry. The equilibrate solutions were tested for their pH and color variations and the appearance

of turbidity.

D. Examination of the Nature of 'Surface Chelation' of Metal Substrates

The nature of chelate coatings developed on the surface of the metal specimens as a result of the above discussed treatment with polydentate ligands was investigated by means of (i) visual examination followed by reflectance infrared examination of the metal surface and (ii) testing the reacting solutions of the chelating agents for pH drop, color change and the appearance of precipitates, if any. If the pH of the equilibrating solution were lowered at the end of the treatment as compared to its pH at the beginning of the experiment, it could be taken to indicate chemical interaction of the chelating agent with the metal substrate.

E. Infrared Reflectance Spectral Examination

The chelate-treated metal coupons were then examined by means of reflectance infrared spectral technique. A Perkin Elmer Model 621 Grating IR spectrophotometer was used, with a reflectance accessory consisting of a Wilkes-Model-12 Double Beam Internal Reflection attachment. The objective in using this method was to obtain qualitative information on the binding of coordinating groups such as hydroxyl, amino, carboxyl, ring nitrogen and a host of other donors with the surface sites of the metals.

F. Splast Tests

Splash tests were conducted on the painted and unpainted test coupons which had been pre-treated with the chelating agents in order to evaluate their corrosion characteristics. The test assembly and procedure were as described before in our Technical Report No. IITRI-C6202-6, under Contract No. N00019-70-C-0180 (1970). The test coupons were suspended around the periphery of the splash test vessel 1/2" above the liquid level. The corrosive brine solutions which consisted of 3.5% aqueous NaCl was

splashed on to the test coupons for five minutes every 55 minutes by means of a semicircular paddle. The test coupons were periodically removed from the test assembly and examined for corrosion damage at the scratch and crevice areas as well as over the paint coating by means of an optical microscope. Observations thus made regarding the onset and development of corrosion were recorded periodically.

G. Primer Coating on the Chelate-Treated Coupons

In order to determine the adhesion of the paint film to the chelate-treated metal substrate and to evaluate the corrosion protection afforded, the test coupons were spray-coated with epoxy primer which was made in accordance with MIL-P-0023377A, and cured for seven days. The general formulation of the epoxy primer is presented in Table I. The inhibitor additive to the primer formulation consisted of a 1:1 mixture of alizarin, strontium chromate.

H. Paint Adhesion Tests

The extent of adherence of the polymeric paint film to the chelated metal surface was determined by means of the angular scribe-stripping technique of Tqoke (Ref. 1). A groove was scribed through the paint film of the test coupon. The cutting tip chosen for making the adherence measurements sliced into the metal at a small angle to the horizontal ($\arctan = 0.1$). The shearing action during scribing causes a strip of paint to detach from metal substrate. The mean width of the strip is determined by means of measurements of micrographs of the grooves.

The experimental procedure consisted in first immersing the primer-coated test coupons in 3.5% NaCl solution for eight days followed by scribing a groove through the paint film by means of the cutting tip. Photomicrographs of the scribed surface were then taken on Polaroid film at about 40 times magnification. In Figure 1, which shows a typical

TABLE I

EPOXY PRIMER FORMULATION

Components	Quantity (grams)
<u>Resin Component I</u>	
Inhibitor compound	12.0
Epon 1001 Resin (75% in Toluol)	18.2
Titanium Dioxide	2.3
Magnesium Silicate (Talc)	5.5
Diatomaceous Silica	2.9
Methyl isobutyl ketone	12.6
Toluene	6.5
	<u>60.0</u>
<u>Curing Agent Component II</u>	
Polyamide Shell Versamid 415	10.7
Toluene	12.9
n-butyl alcohol	8.2
Isopropyl alcohol	8.2
	<u>40.0</u>
Total Weight	<u>100.0</u>

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Figure 1: TYPICAL PHOTOMICROGRAPH

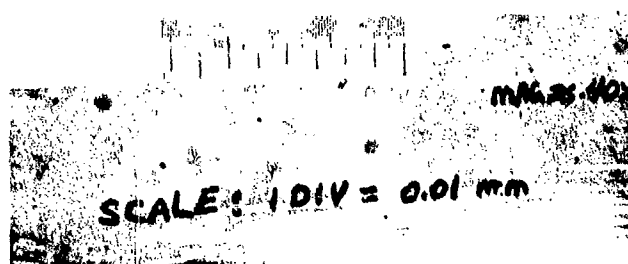


Figure 2: SCALE USED

photomicrograph, 'A' represents the stripping width, B_i is the i^{th} measurement of the amount of paint left on the surface of the coupon (dashed line indicates the boundary). Measurements of 'A' and ' B_i ' were made by using the photomicrograph of a scale that was 1 mm long and was divided in units of 0.01 mm (Fig. 2). The adherence number is given by $A/(A-B)$ and the percent adhesion is given by $(B/A)100$.

I. Potentiostatic Polarization Studies

Cathodic and anodic polarization studies were carried out on the test coupons which had been treated with the candidate chelating agents. The experimental procedure consisted of measuring the currents obtained as a function of the controlled potential applied. A model 4100 Anotrol Research Potentiostat was used. The electrochemical cell for the study consisted of a platinum counter electrode, the test coupon and saturated calomel electrode. All measurements were made at room temperature in an electrolyte medium of 3.5% aqueous sodium chloride. The medium solution was stirred vigorously by means of a magnetic stirrer. The control potential was varied from -2.6V to +2.6V during the course of the polarization study. A schematic diagram of the experimental set-up is illustrated in Figure 3. The controlled potential was varied manually and the cathodic and anodic polarization behavior of the test coupon investigated by measuring the current at each potential.

J. Potentiometric pH Titration

In order to estimate the relative metal-binding affinities of the different chelating groups such as the amino-, carboxylic, hydroxyl and phosphonate, a few preliminary pH titration experiments were carried out. The experimental set-up consisted of a potentiometric pH meter (Radiometer) with a glass-calomel electrode system and a thermostated titration assembly. The actual measurements consisted of determining the hydrogen ion concentration of the chelating agents in the

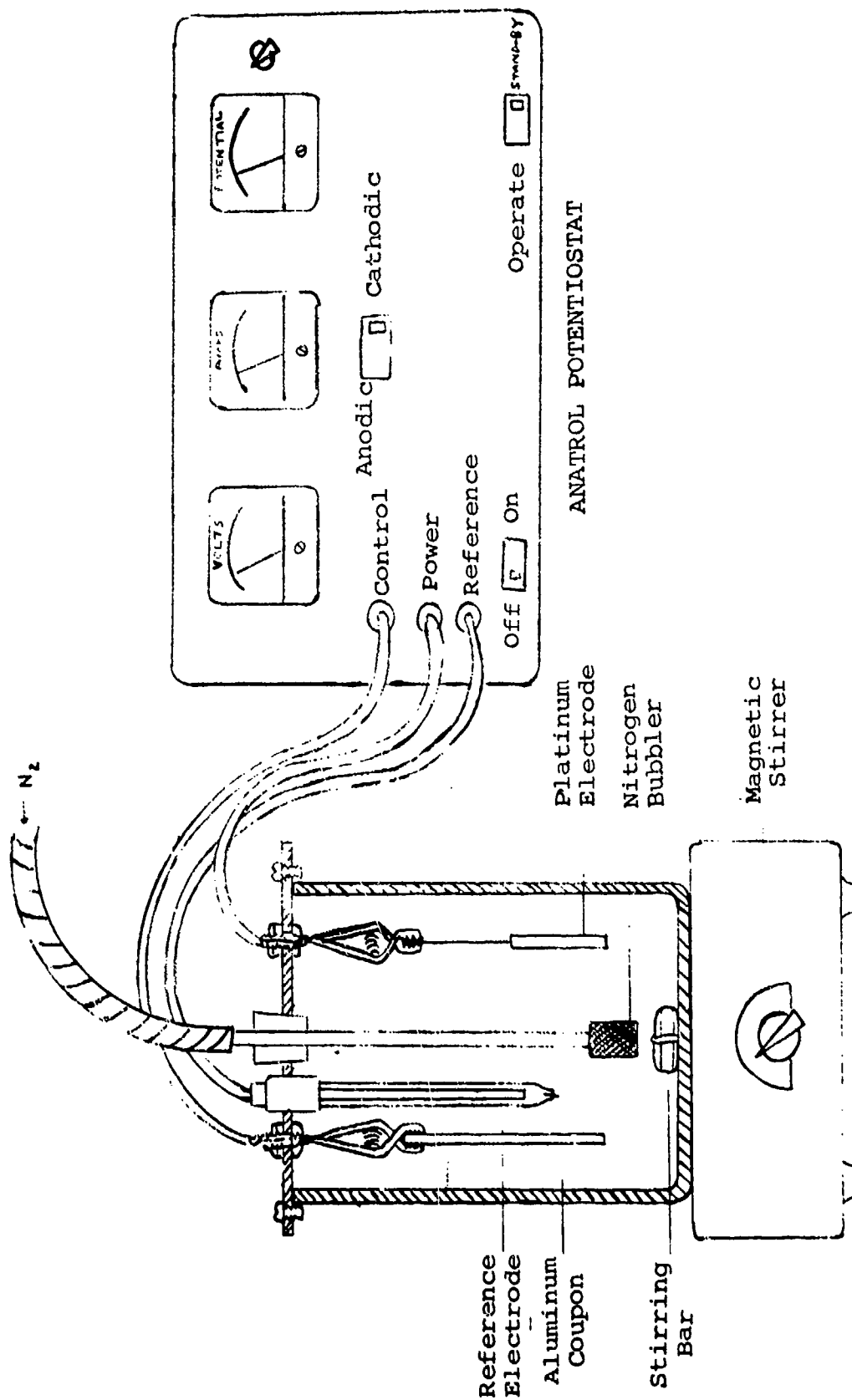


Figure 3

Experimental Set-up For Polarization Studies

presence and in the absence of equimolar amounts of aluminum ion. Titration curves were then traced by using the potentiometric data. Actual titration curves and the qualitative conclusions that were drawn on the basis of the curves are discussed later in this report.

III. RESULTS AND DISCUSSION

A. Interactions of the Chelating Agents with Metal Surfaces

1. pH Effect and Visual Observations

In their reactions with metal ions (and Lewis acids), the chelating agents are considered as Lewis bases. Because of the basic properties of most chelating ligands, they are associated with hydrogen ions over a wide range of pH. Thus the interaction of metal substrate (which acts as a Lewis acid) with a chelating compound could involve the displacement of hydrogen ions from the latter. "Surface chelation" reaction could thus result in a drop in the pH of the reacting solution. It is on the basis of this consideration that the pH variations were tested of the solutions of the chelating agent before and after the treatment of the metal coupons.

In the cases of the aminocarboxylic acids such as DTPA, HEDTA, IMDA and HXG (See Table II) not only was a depression of the solution pH noted but also a blue coloration of the solution. Further, a thin coating on the metal surface was observed which could be the result of some reaction of the chelating agent with the metal. Similar interactions were noted with the aminophosphonic acids. However, visual examination of the specimens treated with citric, tartaric, and mandelic acids did not indicate this type of film formation despite the observed pH effect.

It should be stated that this series of tests provide only a qualitative indication of the interactions of the chelating agents with the metal surface sites. The compounds presented in Table II constitute only a partial list of the candidate chelating agents investigated in this study.

B. Infrared Reflectance Examination

Although the reflectance spectra of the test coupons treated with each of the candidate chelating agents were

TABLE II

INTERACTIONS OF METAL IONS WITH METAL ION COMPLEXES

Concentration = 5% (w/v) aqueous solution;
Duration = maximum 24 hours; Temperature = ambient

OBSERVATIONS ON THE EQUILIBRIUM AND SUBSTRATE

Chelating Agent	Al 204-T3	Al 7075-T6	Stainless Steel #302	Titanium Ti-6 Al-4V
Diethylenetriamine pentaacetic acid, (DTPA; CHELON-60)	pH effect = 1.2 units; solution light blue; thin coating on the metal; (-COO-), (-CH ₂), (-CON) bands	pH effect = 1.0-1.2; solution pale blue; thin coating on the metal; (-COO-), (-CH ₂), (-CON) bands.	pH effect = 0.5-3.7 thin coating indicated; total absorption of infrared	pH effect = 0.1-0.2 visually cannot notice any coating; total absorption of infrared
Ethylenediamine-tetraacetic acid (EDTA)	pH effect = 1.0 unit; infrared spectra as above; thin coating on metal surface	pH effect = 1.0 unit; I.R. spectra same as above.		pH effect = 0.8; total absorption of infrared; no visible coating
Iminodiacetic acid (IMDA)	0.6 pH unit; -COO-band observed; coating indicated	0.6 pH unit; -COO-band observed; coating indicated	0.5 pH unit; no I.R. spectra;	0.6-1.4 pH units; no I.R. spectra;
Dipicolinic acid	1.6 pH unit; COO-band observed; coating indicated	1.6 pH unit; -COO-band observed; coating indicated.		
N-hydroxyethyl ethylene diaminetriacetic acid (MEDTA; CHELON-120)	1.2 pH unit; (-COO-), (-CH ₂) and (-CON) bands; thin coating on metal surface.	1.2 pH unit; (-COO-), (-CH ₂) and (-CON) bands; thin coating on metal surface.	0.3 pH unit; no I.R. spectra.	0.3 pH unit; no I.R. spectra.
N,N-dihydroxyethylglycine (HVG, CHELON-DHG)	1.8 pH units; relatively weak IR spectrum	1.7 to 1.8 pH units; relatively weak IR spectrum	0.6 to 2.1 pH units; no IR spectrum	0.6-2.1 pH units; no IR spectrum obtained with titanium
Citric, Tartaric and Malic acids	0.6 to 1.0 pH units; black flaky particulates; no IR spectrum	0.6-1.0 pH units; flaky black particulates; no IR spectrum	no significant pH effect; no IR spectrum	pH effect 0.2 units; no IR spectrum

TABLE 11 Continued

INTERACTIONS OF CHELATING AGENTS WITH METAL SUBSTRATES

Concentration = 5% (w/v) aqueous solution;

Duration = maximum 24 hours; Temperature = ambient

Chelating Agent	OBSERVATIONS ON THE EQUILIBRATE AND SUBSTRATE			
	Al 2024-T3	Al 7075-T6	Stainless Steel #302	Titanium Ti-6 Al-4V
Aminotris(methylene phosphonic acid) DEQUEST-2000	0.3 pH unit; thin coating on metal surface; weak IR absorption indicating -COOH and P=O bands	0.3 pH units; thin coating on metal surface weak -COOH and P=O bands	no pH effect; no IR spectrum	no significant pH effect; no IR; thin coating indicated
DEQUEST-2006, the penta sodium salt of Deq. 2000	same as above	same as above	pH effect = 0.2 unit	pH effect 0.1 unit
Ethylenediaminetetra-methylenephosphonic acid Potassium salt DEQUEST-2044	no pH effect; thin film on surface. similar IR spectra as above but relatively weaker	no pH effect; IR spectra similar to the above but weaker	no pH effect; no IR spectrum	no pH effect; no IR spectrum
Hexamethylenediamine tetraphosphonic acid Potassium salt (DEQUEST-2054)	no pH effect; thin surface film; IR spectra similar to one above	no pH effect; thin surface film; IR spectra similar to the one above	no pH effect; no IR spectrum	
1-hydroxyethylidene-1,1-diphosphonic acid (DEQUEST-2010)	no pH effect; IR absorption indicates P=O bands; light coating	no pH effect; IR spectra indicates P=O bands	no pH effect; no IR spectrum; light coating visible	no pH effect; no IR spectrum; coating not seen
p-aminobenzoic acid	2.2 pH units; light coating; -COO-band in IR spectrum	2.2 pH units; IR spectra indicates -COO-band		
succinic acid	pH effect = 1.0 unit; -COO-band	pH effect = 1.0 unit; -COO-band		
Salicylhydroxamic acid	pH effect not significant; Total absorption of IR	pH effect not significant; total absorption of IR	pH effect = 1.0 unit; no IR spectrum due to absorption of incident IR	no pH effect; no IR spectral peaks

TABLE II Continued

INTERACTIONS OF CHELATING AGENTS WITH METAL SUBSTRATES

Concentration = 5% (w/v) aqueous solution;

Duration = maximum 24 hours; Temperature = ambient

Chelating Agent	OBSERVATIONS ON THE EQUILIBRATE AND SUBSTRATE		
	Al 2024-T3	Al 7075-T6	Stainless Steel #302 Titanium Ti-6 Al-4V
Hydantoic acid	pH effect = 1.4 units; significant IR spectral peaks of -COO band	pH effect = 1.4 units; significant IR spectral peaks of -COO	no significant pH effect; no IR spectral peaks due to total absorption of incident IR
Bis-salicylaldehyde-ethylenediamine	surface coating indicated on visual examination; IR spectra did not indicate anything	surface coating noted visually; IR spectra was not meaningful	
Acetylacetone	surface coating indicated visually; IR spectra not clear	surface coating indicated visually; no IR spectra	surface coating indicated visually
diethyl-N,N'-bis(2-hydroxyethyl) aminoethylphosphonate (FYROL-5)	no pH effect; surface coating did appear significant; no clear IR spectra	same as with Al 2024-T3	Same as with Al 2024-T3
Maleic acid	pH effect = 1.1 unit significant coating; -COO-bands in IR spectral examination	pH effect=1.1 unit; significant coating; -COO-bands in IR spectral test	no significant pH effect; surface coating not detected either visually or through IR spectra.

recorded, only those treated with some of the ligand systems gave useful information regarding the surface-bound groups. Among the three metal systems investigated, only the aluminum alloys (7075-T6 and 2024-T3) gave reflectance spectra. In the cases of the stainless steel and titanium coupons, there was extremely weak reflectance, possibly due to the nearly total absorption of the incident IR radiation. The use of alternate methods of precleaning procedures and change of alloy samples did not result in any improvement in their IR reflectance. Therefore in future X-ray diffraction techniques should also be adopted.

The satisfactory specimens (belonging to the aluminum alloys) included those which had been treated with amino-carboxylic acids such as DTPA, EDTA, HEDTA and IMDA. Further, the coupons treated with some of the aminophosphonates belonging to the DEQUEST series gave satisfactory reflectance spectra. Figures 4,5,6,7 show the reflectance spectra of aluminum surfaces treated with DTPA, EDTA, CHELON-DHG (Dihydroxyethylglycine) and hydontoic acid in the frequency range of $600-1700\text{ cm}^{-1}$. A discussion of the significant spectral peaks and their functional group assignments is presented.

The reflectance IR of these systems showed spectral peaks at the following frequencies (cm^{-1}): 3200 (broad), 2060-2080, 1570-1600, 1360, 1030, 760-770 and 390. The peak at 1570-1600 is attributed to the antisymmetric carbonyl stretching frequency of the carboxylate group, and the one at 1360 to the C-H bending mode of the $-\text{CH}_2$ grouping. The peak at 1030 is -C-C-N-symmetric stretching of the $\text{N}-\text{CH}_2-\text{CH}_2-\text{N}$ grouping and the one at 760 is the deformation frequency of $-\text{COO}^-$. The fact that the IR-frequencies of all the functional groups of the amino-carboxylate compounds were found to be present in the reflectance spectra of the

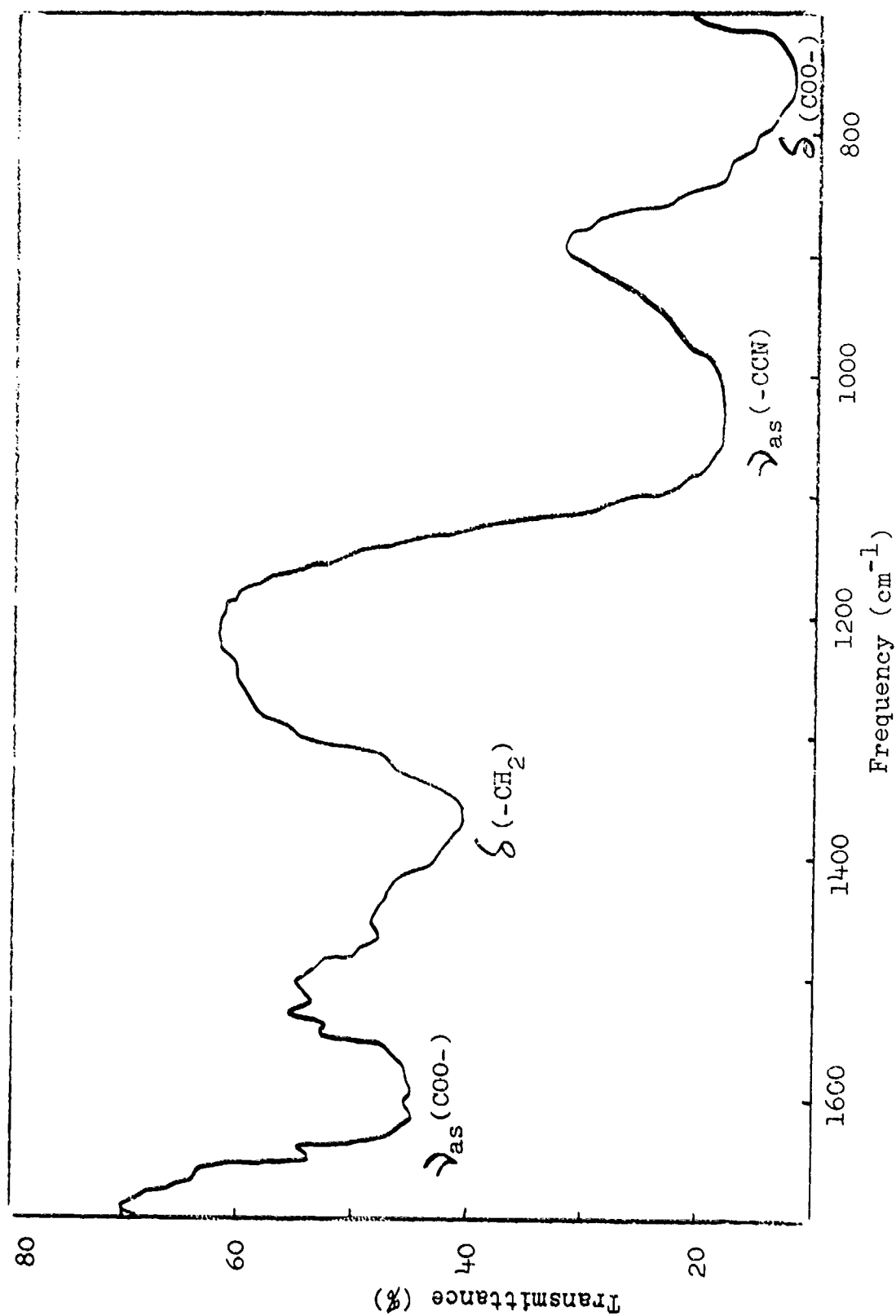


Figure 4. Reflectance IR Spectra of DTPA-Treated Aluminum Surface

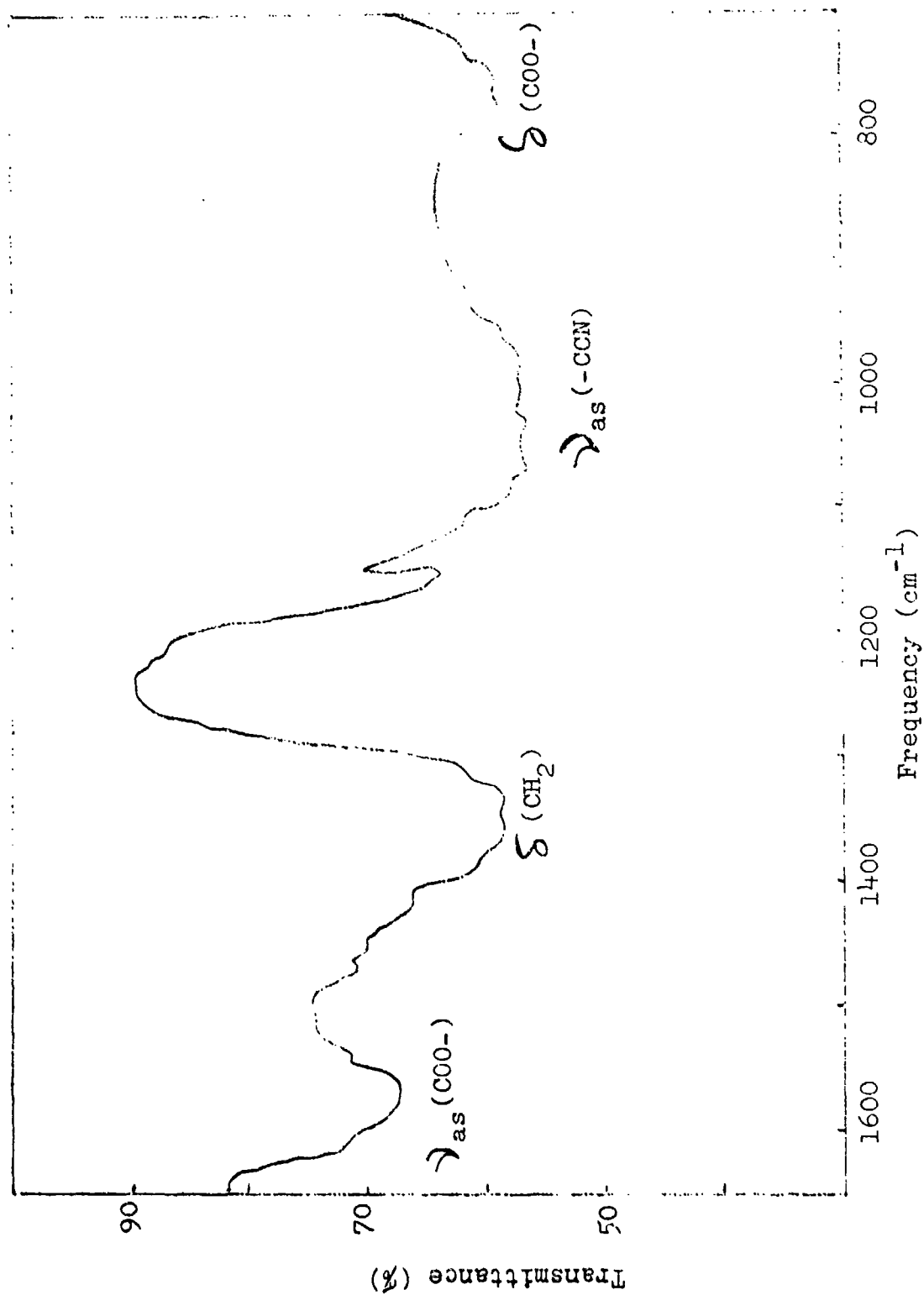


Figure 5. Reflectance IR Spectra of EDTA-Treated Aluminum Surface

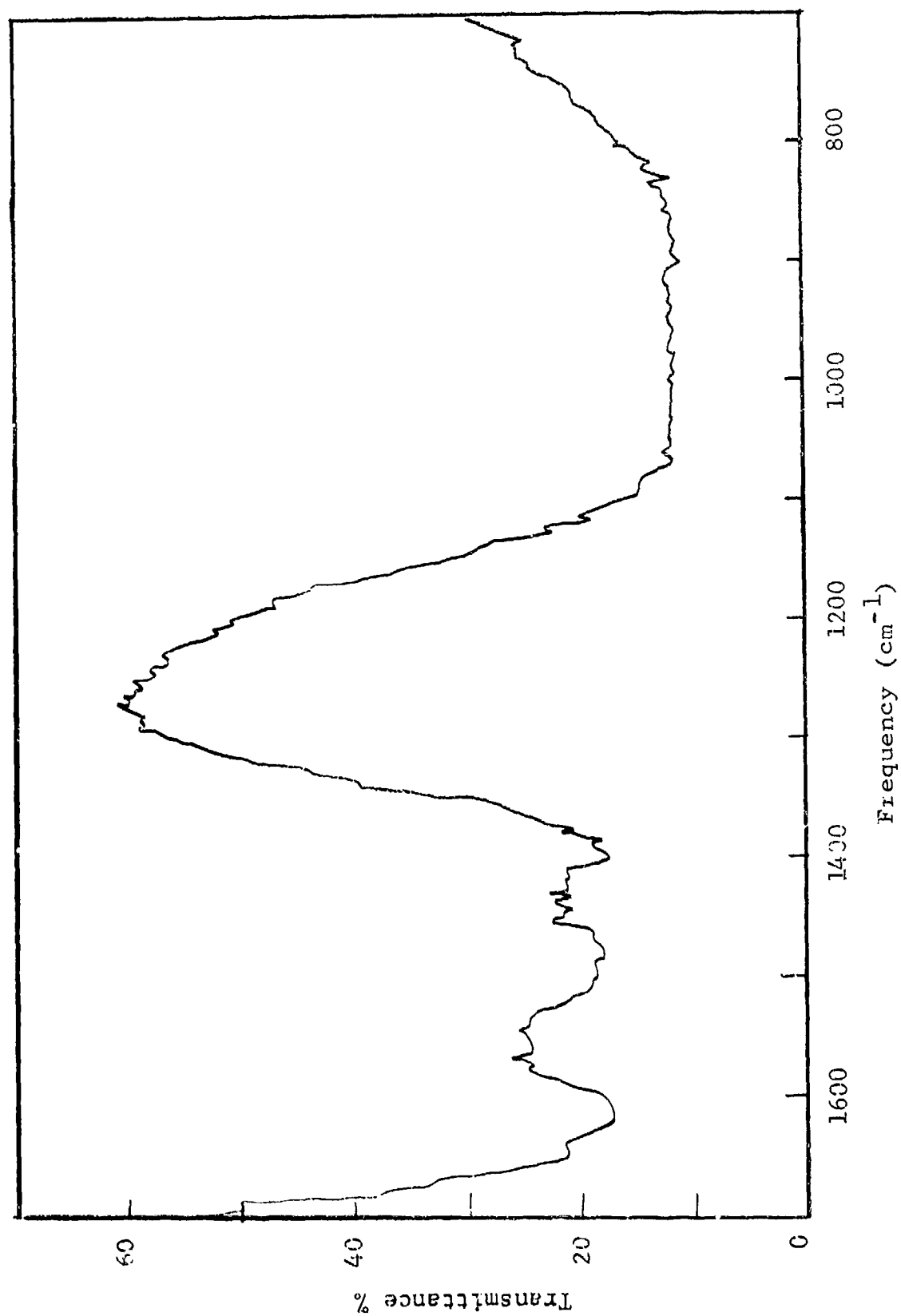


Figure 6. Reflectance IR Spectra of CHELON-DHG Treated Aluminum Surface

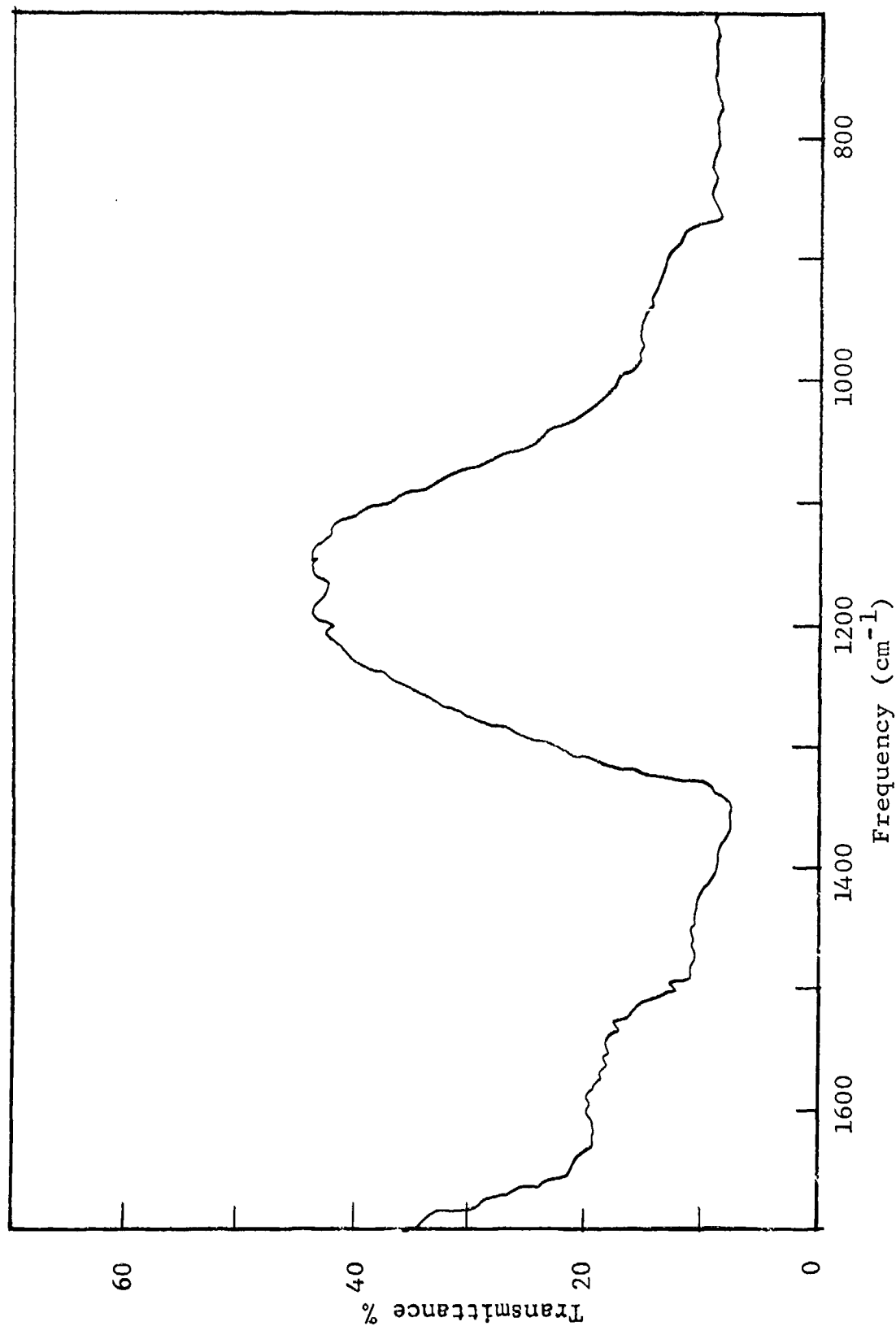


Figure 7. Reflectance IR Spectra of HYDANTOIC ACID Treated Aluminum Surface

test specimens which had been treated with these compounds indicated that they were present possibly as surface-bound species in mono or multi-molecular layers. Because of the intensity of absorption and the well-defined nature of the spectral peaks, it would be reasonable to make a qualitative estimate that these polydentate chelating agents were bound to the metal surface in more than a mono-layer.

3. Polarization Studies

Samples of the chelating agent-treated and untreated coupons of the alloy systems were tested for their anodic and cathodic polarization characteristics by using the experimental set-up described earlier in this report. In the electrochemical cell assembly, the test coupons functioned as the working electrode. In these experiments, the electrolyte solution consisted of 0.6M NaCl (3.5% W/V solution) and the total area of the test coupon involved in the electrochemical cell was 10.65 sq. cm.

Since the chelate-treatment studies were of an exploratory nature in which a number of the candidate compounds were being screened, no detailed analysis of polarization data were undertaken. Further, only those systems were considered which appeared promising on the basis of (i) pH effect (ii) visible surface coating and (iii) reflectance infrared spectra.

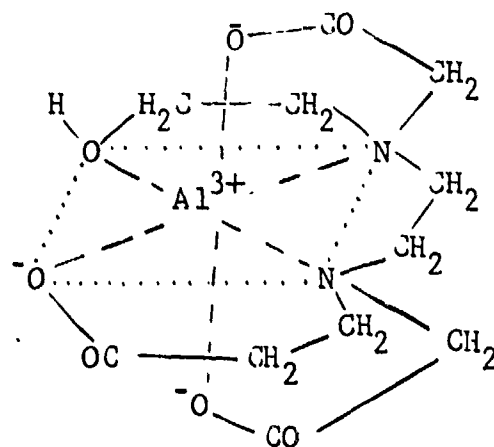
Corrosion potentials of the treated and untreated test specimens were examined on the basis of the potentiostatic data. Shifts in the corrosion potentials of the specimens as a result of the chelating agent treatments were estimated. In this study, potential shift, ΔV to a higher (more positive) potential was taken as an indication of the effectiveness of the chelate-binding. Although a number of chelating agent systems showed satisfactory adhesion and corrosion inhibition characteristics (as will be seen from the results in the following sections), they did not indicate significant

shifts in corrosion potentials. This anomalous behavior might be due to the possibility that these chelating agents were not strongly coordinated to the metal surface but were loosely held and were therefore easily washed away into the electrolyte medium. Only a few of the systems which showed potential shifts to more noble values than the untreated specimens are presented in Table III.

D. Nature of Interaction of the Chelating Agents with Aluminum

Potentiometric titration curves for the reactions of aluminum ion with (i) hydroxyethylethylenediaminetriacetic acid (HEDTA), (ii) sulfosalicylic acid (SSA), (iii) succinic acid (SA), (iv) diethanolaminemonomethylenephosphonic acid (DEMPA) are presented in Figures 8, 9, 10 & 11. In these plots, the abscissa represents 'a', the number of moles of base added per mole of the chelating agent or the total metal salt, and the ordinate represents the measured pH values.

Consideration of the Al(III)-HEDTA system with inflections at 3 and 4 equivalents of base (Figure 8) indicates that the aluminum ion interacts strongly with all the three carboxylic acids of the chelating agent in pH range 2-4, and further reacts with the hydroxyl group in the pH range 4-7. It is valid to rationalize that the metal ion is bound by two amino-nitrogens, the three carboxylate oxygens and possibly by the hydroxyethyl group as follows:



Chelation of Al(III) with HEDTA

TABLE III

SHIFTS IN THE CORROSION POTENTIALS BY SURFACE CHELATION

Electrolyte Medium = 0.6 M NaCl; Test specimen area = 10.65 cm².
 Potential of Al 2024-T3 = -1.9V; Stainless Steel = 1.0V (VS. SCE)

Chelating Agent	SHIFT IN CORROSION POTENTIAL (VOLTS)	
	Al 2024-T3	Stainless Steel
Hydantoic Acid	0.5	0.4
Diethylenetriaminepentaacetic acid (DTPA)	0.6	0.4
Hydroxyethylethylenediamine-triacetic acid (HEDTA)	0.6	0.5
Aminotrismethylenephosphonic acid	0.6	0.3

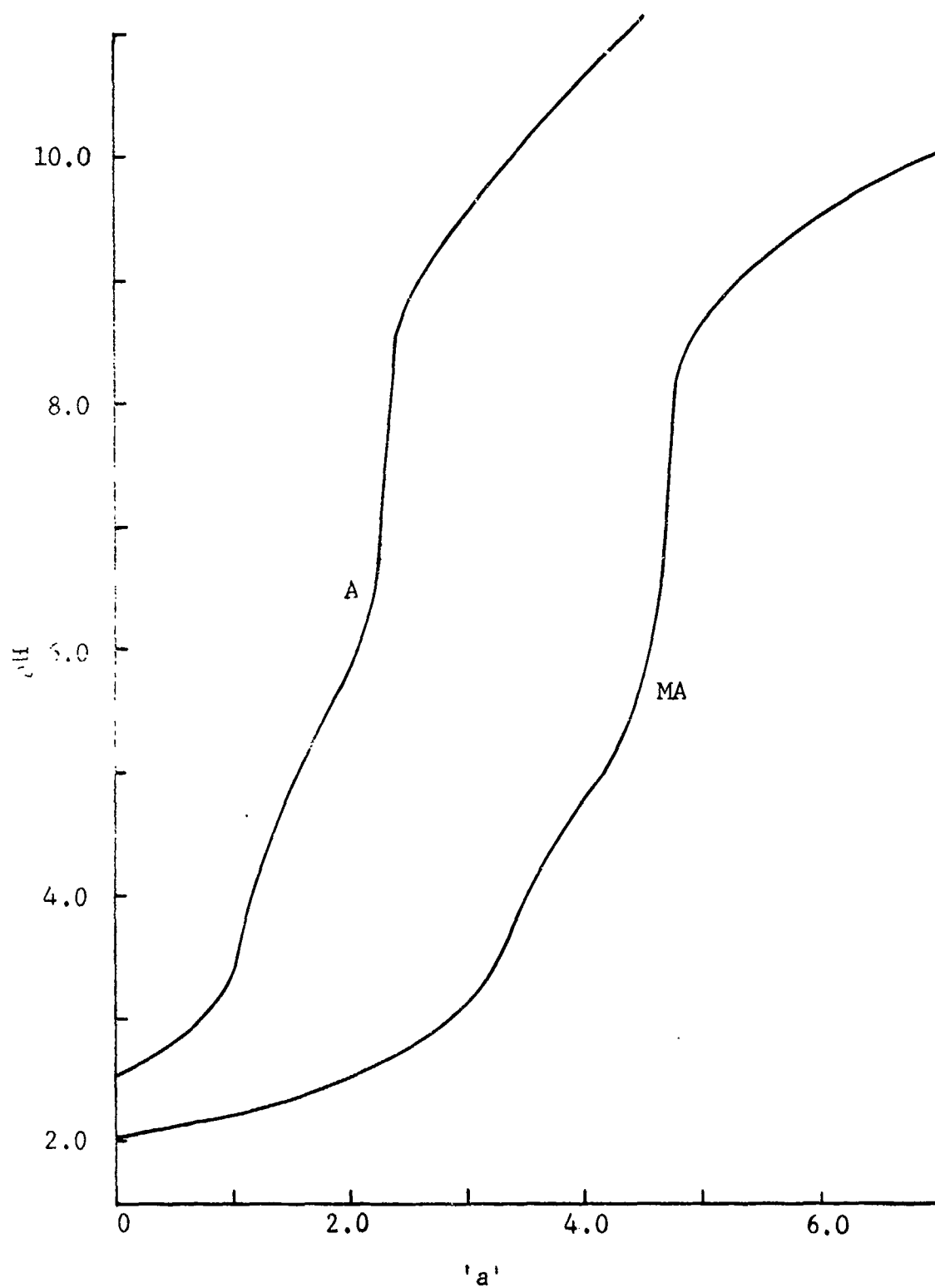


Figure 8
 Chelation of Al(III) With HEDTA A = HEDTA;
 MA = 1:1 Al(III) - HEDTA System. a = No. of
 Moles of Base Per Mole of Ligand and Al(III).

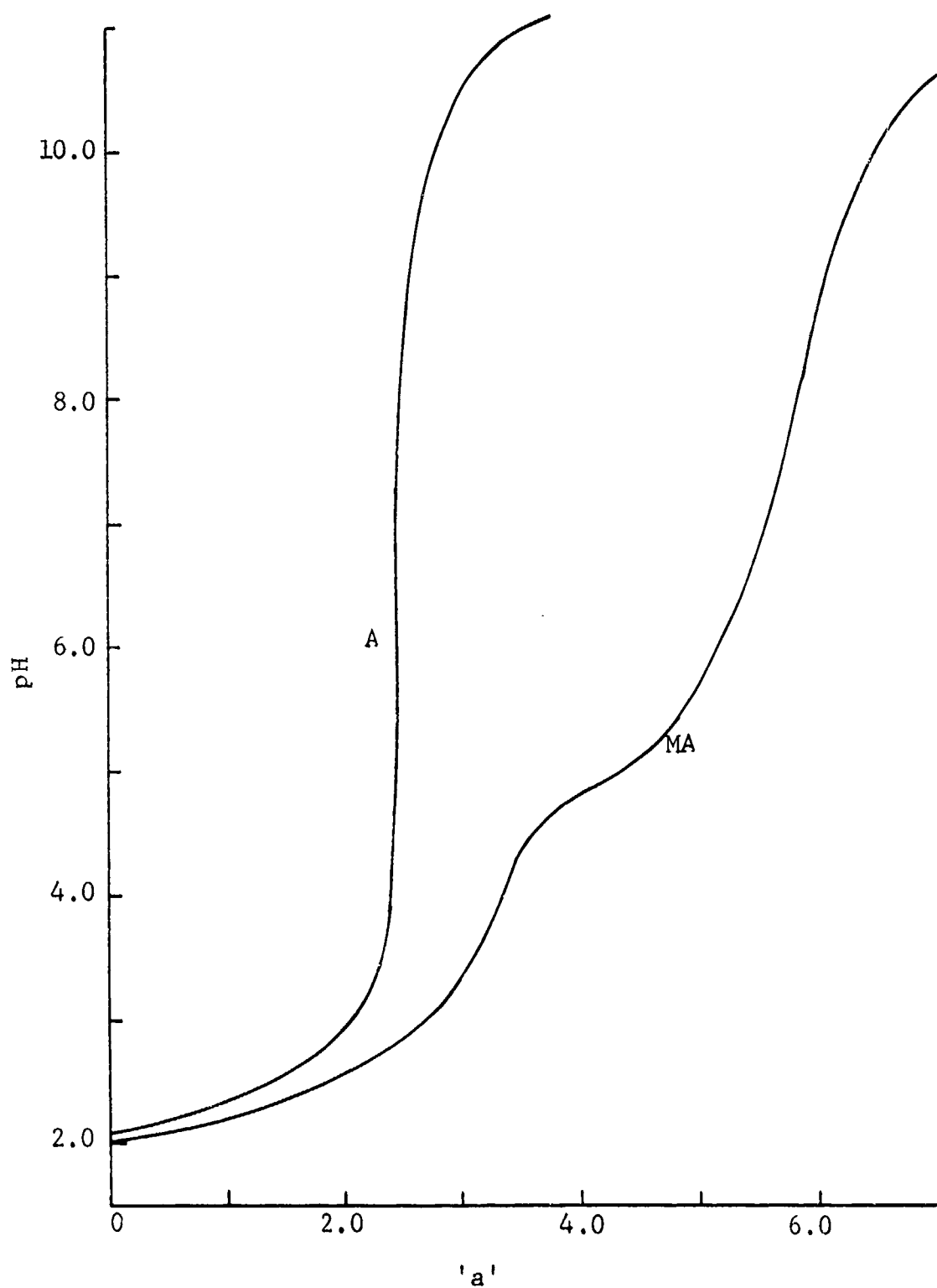


Figure 9

Interaction of Al(III) With SSA; A, Free SSA;
MA, 1:1 Al(III) - SSA System.

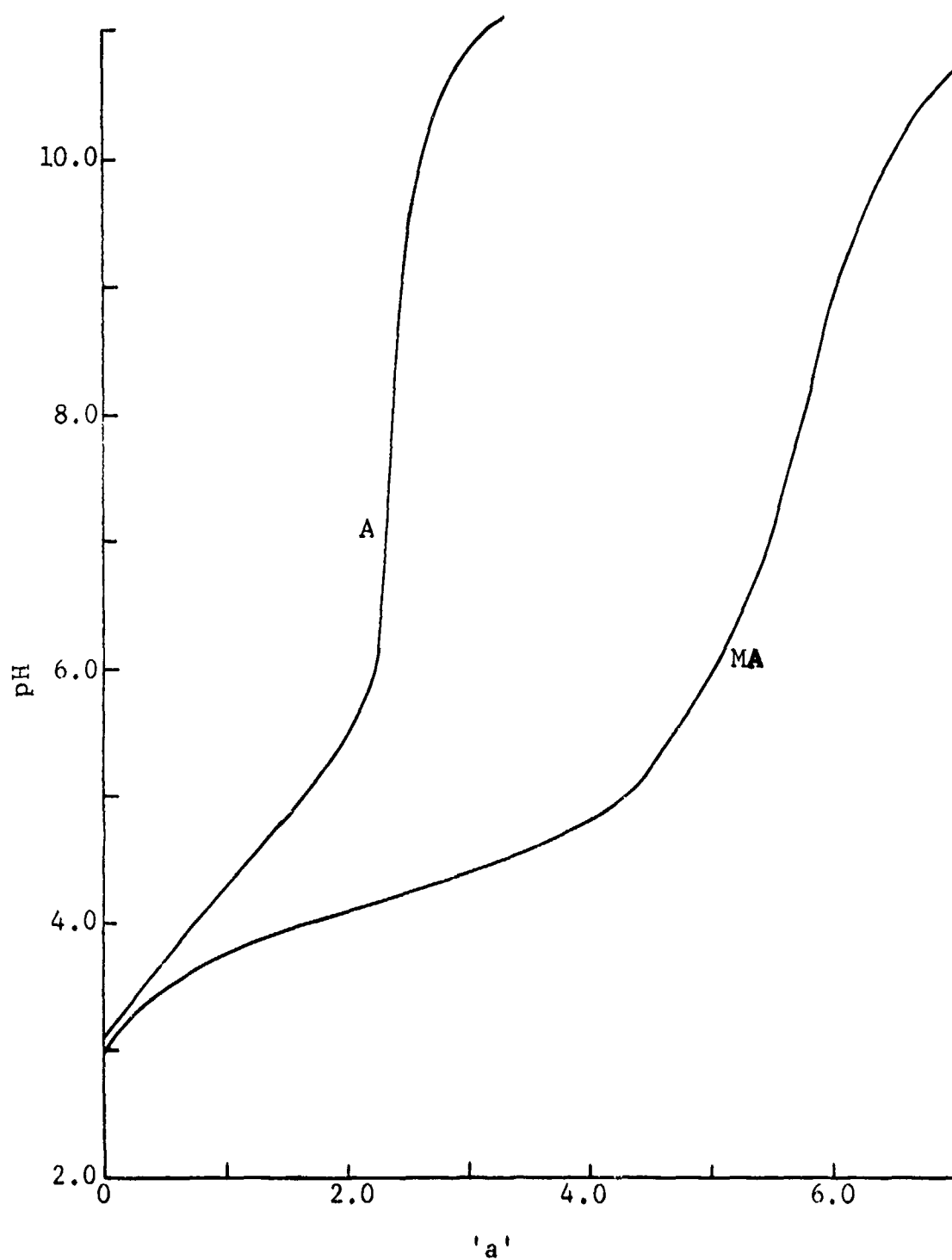


Figure 10

Interaction of SUCCINIC ACID With Al(III) Ion.
A, Free SUCCINIC ACID; MA, Al(III) - SUCCINIC
ACID (1:1) System.

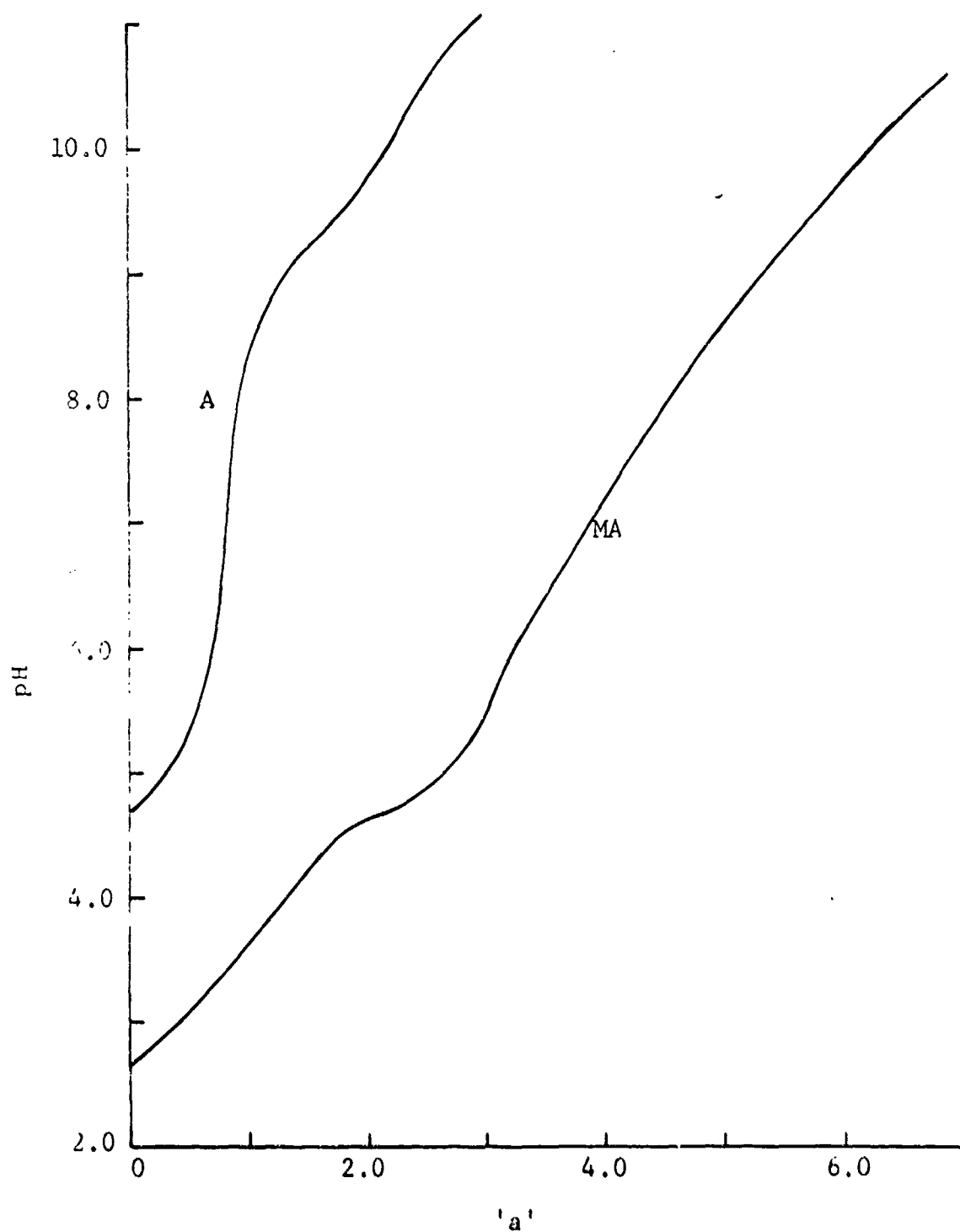
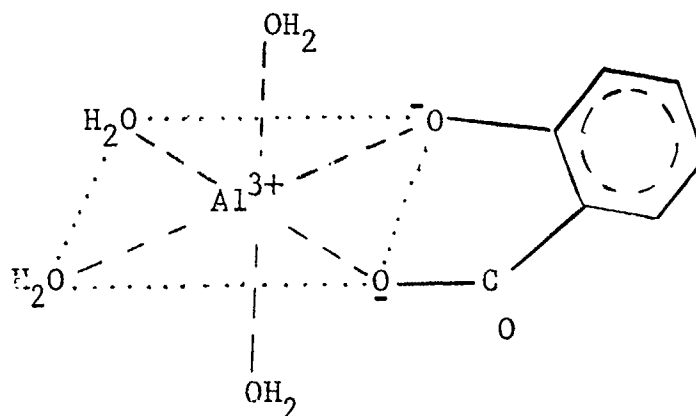


Figure 11

Chelation of Al(III) Ion With DEMPA;
A, Free DEMPA, MA, 1:1 Al(III) - DEMPA

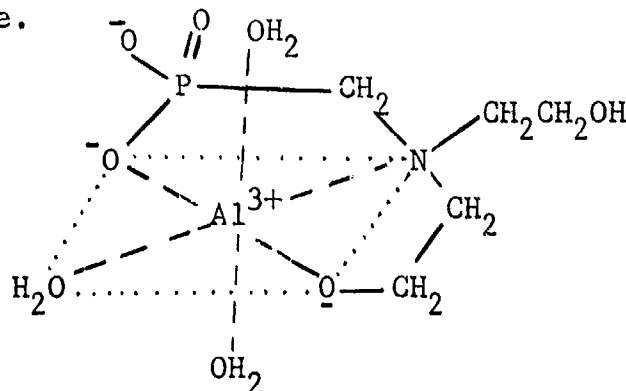
Figure 9 indicates that sulfosalicylic acid binds strongly with aluminum ion in the pH range 2-4 and that the carboxylic and the phenolic hydroxyl group are both involved in the metal binding. This is structurally illustrated below:



Binding of Al(III) with SSA

Succinic acid, which is a simple dicarboxylic acid, does not exhibit strong binding tendency toward aluminum. The titration curve (Figure 10) indicates extensive hydrolysis of the metal due to weak chelation by mere carboxylate groups.

Consideration of the titration curve of Al(III)-DEMPA system indicates that the metal ion is strongly chelated and that the phosphonate and one of the hydroxyethyl groups are involved in chelation. The coordinate-binding of aluminum by this chelating agent is illustrated by the following structure.



Chelation of aluminum with DEMPA

The potentiometric data and the above discussions have indicated that chelating agents containing aminocarboxylic, amino-hydroxycarboxylic and aminophosphonic groups have the property of strong metal-binding for aluminum. In the case of bi-dentate compounds (having only two binding groups), it is not satisfactory to have merely carboxylate functionality. The combined presence of a phenolic hydroxyl group such as in sulfosalicylic acid seems necessary for satisfactory metal chelation. In extrapolating the above observations on metal chelation to the actual metal surface treatment, the solution pH and concentration of the chelating agent should be carefully chosen in order to enable a strong and favorable surface chelation reaction. Further the above potentiometric data provide an insight into the possible nature of metal surface binding that can be expected from the individual chelating agent.

Similar studies on the other two metal systems, viz., iron and titanium could not be undertaken during the current project due to lack of time. Some of the important ligand systems will be investigated in future projects.

E. Paint Adhesion

Procedures for the preparation of the chelate-treated metal coupons and paint adhesion measurements were described earlier in this report. Results of adherence tests on all the alloy systems, viz., Al 7075-T6, Al 2024-T3, Ti-6Al-4V and stainless steel #302 are presented in Table IV. The adhesion characteristics of the aluminum alloys which had been treated with polydentate chelating agents such as the aminopolycarboxylic acids (CHELON series) and the aminophosphonic acids (DEQUEST series) were in general satisfactory and were comparable to conventional chromate-treated (CHEMRITE) samples. In the cases of the titanium and stainless steel alloys, although the DEQUEST series did not

Table IV

PAINT ADHERENCE ON CHELATE-TREATED ALLOY SURFACE

Chelating Agent	Aluminum Al2024		Aluminum Al7075		Titanium Ti-6Al-4V		Stainless Steel #302	
	Adherence No.	% Adhesion	Adherence No.	% Adhesion	Adherence No.	% Adhesion	Adherence No.	% Adhesion
DEQUEST-2005	16	100	100	100	21	4.0	75	
DEQUEST-2000	4.0	94	11	91	42	6.3	38	
DEQUEST-2010	5.0	75	4.0	75	42	1.6	60	
DEQUEST-2054	5.0	80	5.0	80	60	2.5	69	
DEQUEST-2044	5.0	80	3.3	70	50	3.2	88	
CHELON-80	10.0	90	2.0	50	40	8.0		
				15.0*	93*			
CHELON-120	10.0	90	11.0	90	50	5.5	82	
				11.0*	91*			
Dipicolinic acid (DPA)	2.0	50	2.0	50	83	8.0	88	
CHEM-RITE	5.0	80	6.3	84	89	5.0	80	
				14.0*	93*			
Sulfosalicylic					50	4.7	79	
Mandelic	6.0	83	6.0	83	50	8.5	88	
Iminodiacetic acid	4.0	75	3.0	67	75	4.2	76	
				6.0*	83*			
Nitrilotriacetic acid	12.0	92	12.0	92	93			
EDTA	1.7	41	2.0	50	90			
Tartaric acid	15.0	94	50	98				
Citric acid	7.6	87	7.6	87				
Malic acid	10	90	15	93				
CHELON-DEG	3.0		5.2					
dl-Alanine								
PYROL-6	7.3	86	8.5	88	90	8.5	88	
DPP	8.0	88	7.5	87	83	9.0	89	
Hydantoic	1.9	47	1.6	40	80	1.9	47	
BSED	13.0	92	4.0	75	73	7.3	86	
Glycolic								
dl-Glutamic					50	19.0	95	
Anthranilic acid					50	6.0	83	
Maleic acid					90			
Malonic acid					83			
Glycine					77			
					55	13.3	93	

Table IV (Cont.)
PAINT ADHERENCE ON CHELATE-TREATED ALLOY SURFACE

Chelating Agent	Aluminum Al2024		Aluminum Al7075		Titanium Ti-6Al-4V		Stainless Steel #302	
	Adherence No.	% Adhesion	Adherence No.	% Adhesion	Adherence No.	% Adhesion	Adherence No.	% Adhesion
SHA	40	98	25	96			13.3	93
Fyrol-Bis-Beta	5.0	80	7.0	86				
Pyrocatechol	10.0	90	7.3	86				

* 3/8" thick coupons

ABBREVIATIONS

DEQUEST-2000 aminotris(methylene)phosphonic acid
 DEQUEST-2006 penta-sodium salt of DEQUEST 2000
 DEQUEST-2010 1,hydroxyethylidene-1,1-diphosphonic acid
 DEQUEST-2041 ethylenediaminetetra(methylene)phosphonic acid
 DEQUEST-2044 potassium salt of DEQUEST-2041
 DEQUEST-2054 potassium salt of hexamethylenediaminetetra-phosphonic acid
 CHELON-80 Na-salt of diethylenetriaminepentaacetic acid
 CHELON-120 Na-salt of N-hydroxyethylethylenediamine-triacetic acid

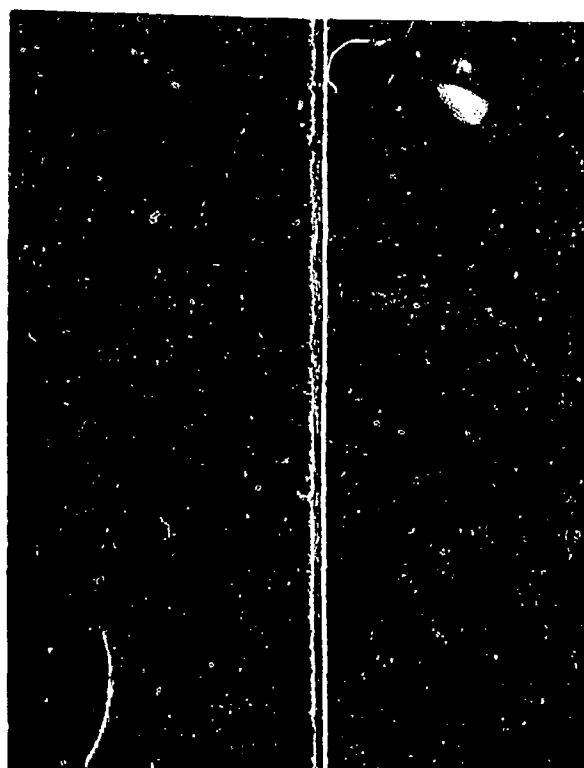
Na-salt of N,N-dihydroxyethyl glycine
 ethylenediaminetetraacetic acid
 diethyl-N,N-bis(2-hydroxyethyl) aminomethylphosphonate
 diphenylphenylphosphonate
 bis(salicylaldehyde)ethylenediimine
 salicylhydroxamic acid
 Bis-p-chloroethylvinylphosphonate
 conventional chemical conversion coating

show any promising results, the aminocarboxylic acids (CHELON series) showed adhesion characteristics somewhat comparable to the conventional CHEMRITE coating. Photographs (Figures 12-13) of the metal coupons which had been chelate-treated and primer-coated are shown below in order to illustrate their paint adhesion characteristics. On the basis of a consideration of the molecular structures of the chelating agents which were found to result in good paint adhesion (See Table IV and the photographs), it may be stated that the chelating agents containing hydroxy group in combination with carboxylic, aminocarboxylic and aminophosphonic groups were satisfactory in surface-binding and promoting adhesion.

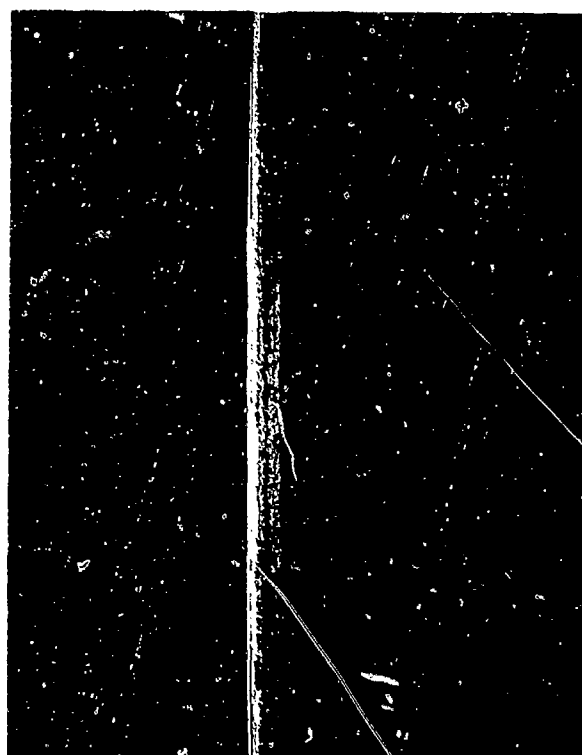
It should also be pointed out that blister formation on the paint film took place in a number of instances in the case of stainless steel and titanium after they had been exposed to salt solution spray for a few days. This phenomenon was noted both in the case of the conventional chromate-treated and some of the chelate-treated systems as is illustrated by the photographs (Figure 14). No corrosive damage occurred underneath the blisters and the blisters disappeared on removing the test coupons from the salt splash unit and drying. It will be necessary to determine, if possible, the conditions that favor such blister formation and to eliminate them in future studies.

F. Evaluation of Corrosion Characteristics (i) Corrosion Inhibition of Chelate-Treated Unprimed Metal Specimens

Although the evaluation of corrosion characteristics of the chelate-treated coupons was carried out essentially only after they had been primer-coated with epoxy primer, a few rapid corrosion tests were also conducted on unprimed test coupons. This series of experiments were undertaken in order to evaluate the nature of corrosion protection afforded by the chelating agent. Aluminum 7075 and 2024 alloy coupons were used and a few selected chelating agents



Stainless Steel #302; Pretreated with Conventional CHEMRITE; Epoxy Primer Coated; Adherence no = 5.0 (good adhesion)



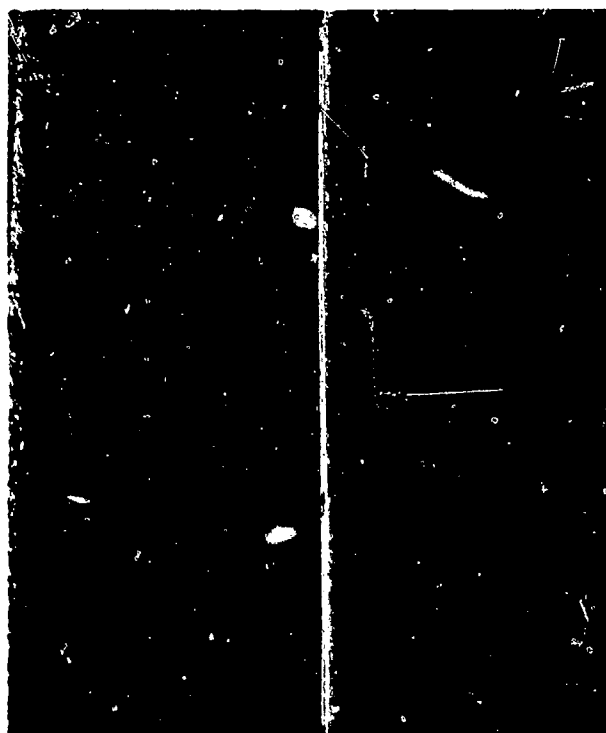
Ti-6Al-4V Coupon Treated with Alanine; Epoxy Primer Coated; Adherence no = 6.0 (good adhesion)

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Figure 12

Stainless Steel #302; Pretreated with Malic Acid; Primer Coated; Adherence no = 8.5 (very good adhesion)



Stainless Steel #302; Pretreated with Dihydroxyethylglycine (CHELON-DHG); Primer-Coated; Adherence no = 9.0 (very good adhesion)



Ti-6Al-4V Coupon Treated with DEQUEST-2000; Epoxy Primer Coated; Adherence no = 1.4 (poor adhesion)

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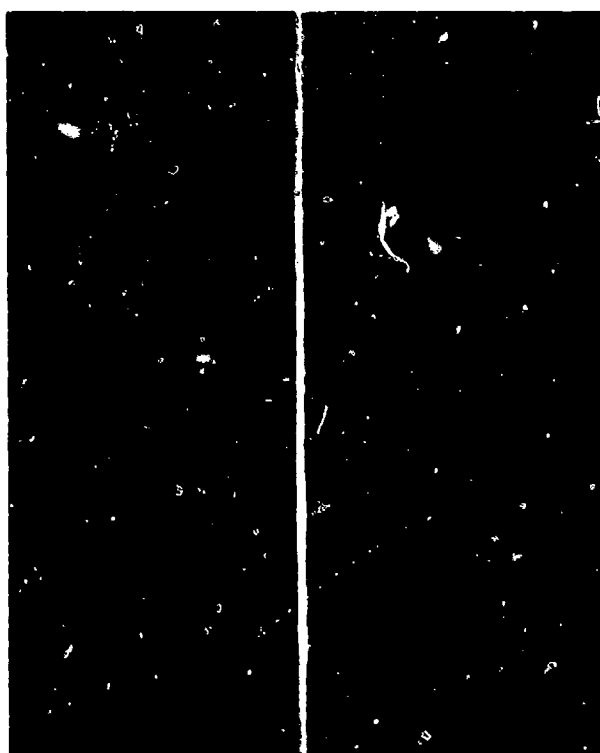
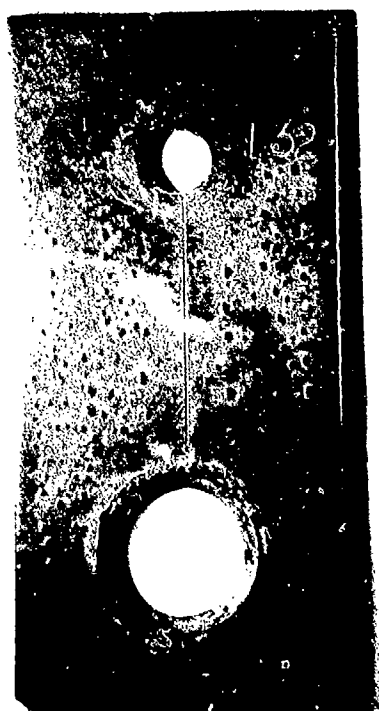


Figure 13

Al 2024-T3 Coupon Treated with Malic Acid; Epoxy Primer Coated; Adherence no = 10.0 (good adhesion)



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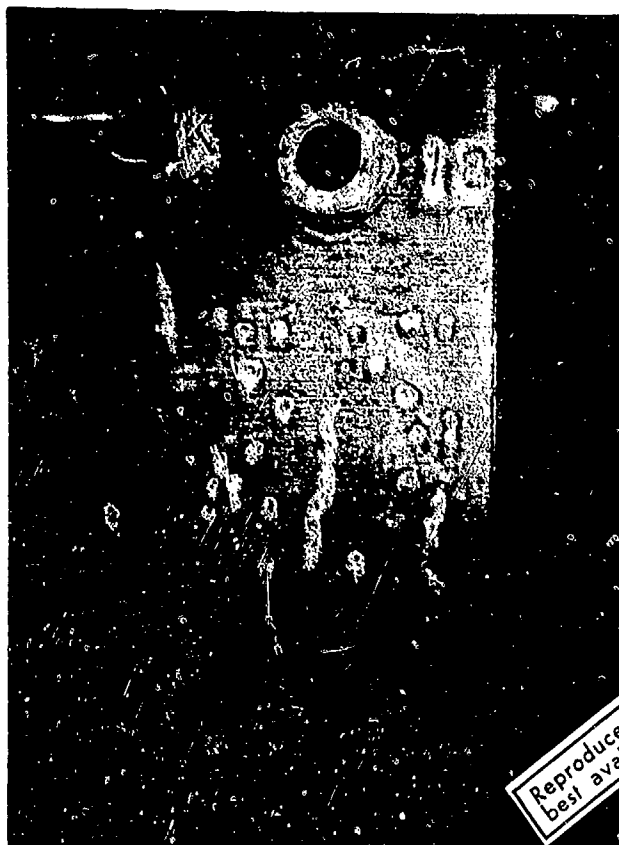
Stainless Steel #302; Pretreated with
CHELON-DHG; Primer Coated; Blister
Formation.

Stainless Steel #302; Pretreated with
Conventional CHEMRITE; Primer Coated;
Blister Formation

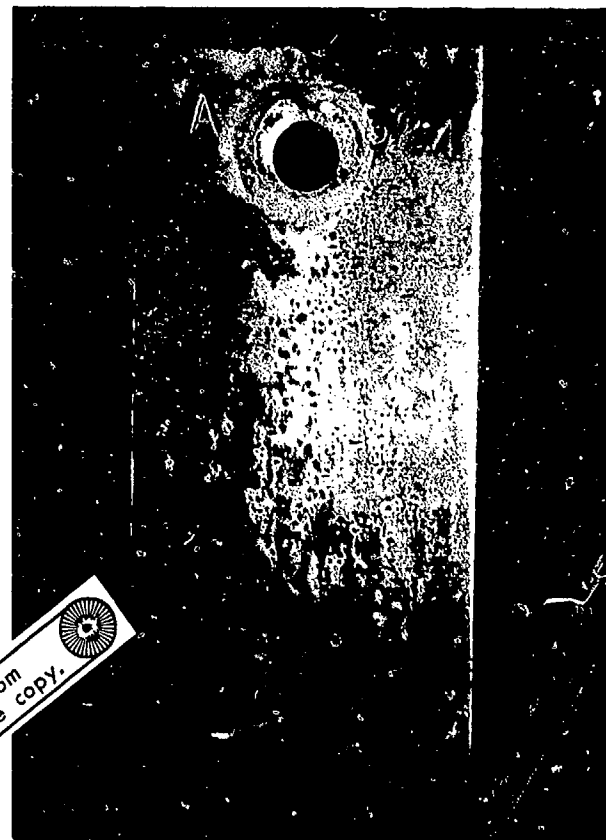


Figure 14

Stainless Steel #302; Pretreated with
Malic Acid; Primer Coated; Blister
Formed Lightly Along Edges Only



Corrosion of Aluminum Coupon
Pretreated with p-aminobenzoic
Acid; Exposed to 96 Hours of
Salt Spray



Corrosion of Aluminum Coupon
Pretreated with CHEMRITE; Exposed
to 96 Hours of Salt Spray

Figure 15

coupons were removed from the splash test unit periodically and examined under an optical microscope for corrosion of the metal. Exposed metal portions in the scratch, and crevice areas were examined and the observations recorded for each one of the chelating agent system and the metal alloy system. In the corrosion tests, each of the alloy systems, viz., Al, Ti and Stainless Steel, test coupons pretreated with the conventional CHEMRITE and coated with epoxy primer were also included in order to provide a comparison.

Results of the corrosion tests on aluminum alloy samples have indicated that the two classes of polydentate chelating agents, viz., aminopolycarboxylic and aminophosphonic acids were comparable to the chromate-based CHEMRITE in affording corrosion protection. Relatively more satisfactory corrosion protection was noted for the Al 2024 alloy coupons than for the Al 7075 systems. The aminophosphonic acids (DEQUEST series) showed greater corrosion protection than the aminocarboxylic acids. Among the other ligands, glycine and p-aminobenzoic acid showed the most satisfactory corrosion inhibition characteristics. These two were comparable to the aminophosphonic acids.

In the cases of acetylacetone bis(salicylaldehyde)ethylene-diimine, corrosion of the crevice area was more significant than in the scratch area. In general, the relatively less satisfactory corrosion inhibition observed in the cases of these two systems might be attributed to their possible incomplete interaction with the metal surface. It was believed that proper experimental conditions would have to be worked out for an efficient covalent interaction of the two ligands with the metal surface. Both these ligands are capable of forming sparingly soluble, covalent chelates with aluminum. Research work should be undertaken toward this objective in future studies.

Corrosion tests with titanium (Ti-6Al-4V) and Stainless Steel #302 test specimens have in general shown remarkable corrosion inhibition characteristics under conditions of salt splash identical to those of aluminum. However, in the cases of both the alloys, majority of the chelating systems including the chromate-based coating system showed blistering of the epoxy primer film on the surfaces of the metals. Among the two alloy systems, the blistering phenomenon was more common and severe with the stainless steel coupons. It was believed that such a predominant occurrence of the film damage could be attributed to (i) the surface conditions of the alloy specimens obtained from the manufacturers, and (ii) the pre-cleaning procedures necessary for a proper preparation of the metal surface. Therefore in future studies research effort should be directed toward a preliminary examination of the surfaces of the alloy specimens and effective pre-cleaning methods.

IV. CONCLUSIONS

Exploratory investigations of a number of different polydentate chelating agents for the chemical treatment of metal surfaces have indicated that there is significant surface binding of the aluminum alloys (7075 and 2024) by aminocarboxylate, hydroxyaminocarboxylate and aminophosphate ligands. On the basis of reflectance infrared spectral examination, these ligands were detected qualitatively to be in multi-molecular layers on the metal surface. Although similar interactions were suspected to be taking place with titanium and stainless steel, unequivocal experimental evidence could not be established. Results of potentiostatic polarization studies and corrosion tests (of unprimed metal coupons) have indicated that the surface-bound chelates were loosely held. However, the paint-adhesion and corrosion inhibition characteristics of aluminum alloys (7075 and 2024) which had been pre-treated with aminophosphonic and aminocarboxylic acids compared favorably with those pretreated with chromate-based CHEMRITE. Although the chelate-treated titanium and stainless steel alloys showed satisfactory adhesion and corrosion-resistance characteristics, blistering of the paint film occurred in the majority of the systems. It was believed that this could be attributed to the surface conditions of the alloy specimens received from the manufacturer.

A. Recommendations for Future Work

The exploratory investigations that were conducted in the current project have led us to believe that the area of "surface chelation of metal substrates for corrosion inhibition and adhesion promotion" has great potential. In continuation of our present work, it would be profitable to direct future work toward two major goals, viz., (i) to optimize the important experimental parameters for a strong

surface chelation by the promising polydentate chelating agents and (ii) to investigate chelating agents that could promote covalent-type of strong chemical binding with the metal surface and to optimize the experimental conditions. Further, it is important to investigate the nature and extent of surface-binding as a function of the functional groups and molecular backbone of the chelating agents in order to enable us to predict molecular structures which would be most efficient for metal surface treatment. Finally, the chemical interaction and adhesion of epoxy and polyurethane types of primers with the surface-bound chelating agents should be investigated in order to determine the optimum combination of systems and conditions for greatly improved paint adhesion and corrosion inhibition.

APPENDIX A

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM

Chelating Agent =

CHEMRITE

Conditions =

Concentration = 5% Aqueous

Temperature = ambient;

pH =

Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	A1 2024 - T3	A1 7075 - T6
7-20	Paint film intact; no corrosion in the scratch but a few sites developing on the crevice area.	Paint film intact; no corrosion of the scratch area; slight corrosion at the crevice area.
27-41	Paint film intact; no corrosion of the scratch but slight corrosion at the crevice	Film intact; no corrosion at the scratch; slight corrosion at the crevice area.
49-61	Paint film O.K.; no visible corrosion of the scratch; significant corrosion at bottom of the crevice.	Paint film O.K.; potential corrosion sites appearing in the scratch; severe corrosion at the bottom of the crevice area.
69-75	Paint film O.K.; slight to moderate pitting corrosion of the scratch and significant pitting corrosion of the crevice area.	Paint film O.K.; moderate to severe pitting corrosion of the scratch; the crevice area badly corroded.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM

Chelating Agent =

Conditions =

NITRILOTRIACETIC ACID (NTA)

Concentration = 5% Aqueous

pH = 8.0-8.25

Temperature = ambient;

Primer Coating = Epoxy

T E S T E V A L U A T I O N	
TIME (Days)	
7-13	AL 2024 - T3 Primer coating intact; no corrosion in the scratch or crevice areas.
25-35	AL 7075 - T6 Primer film intact; slight pitting corrosion in the scratch and crevice areas.
42-49	Primer stayed intact; but corrosion pits were developing in the scratch and crevice areas. Slight blister formation on the back of the coupon; slight to significant pitting in the scratch and crevice areas respectively.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM

Chelating Agent =

Conditions =

N-HYDROXYETHYLETHYLENEDIAMINETRIACETIC ACID (HEDTA)

Concentration = 5% Aqueous

pH = 12.1

Temperature = ambient;

Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	AL 2024 - T3	AL 7075 - T6
7-13	Paint film intact; no corrosion in the scratch; but some pits developing at bottom of crevice.	Paint film intact; no corrosion at either the scratch or crevice areas.
25-35	A few small blisters on the paint film; very slight pitting corrosion at both the scratch and crevice area.	Paint film intact; pits developing in both the scratch and crevice areas.
42-49	Slight blistering of paint film along the scratch area; slight pitting at the scratch area; severe pitting in the crevice area.	Paint film intact; moderate pitting in both the scratch and the crevice areas.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM
 Chelating Agent = PYROCATECHOL
 Conditions = Concentration = 5% Aqueous
 pH = 8.0-7.8
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	Al 2024 - T3	Al 7075 - T6
7-20	Paint film intact; no corrosion of the scratch or crevice area.	Paint film intact; no corrosion of the scratch or crevice areas.
27-41	Paint film intact; no corrosion of the scratch but a few developing sites for corrosion are appearing in the crevice	Paint film intact; no corrosion of the scratch; a few developing sites for corrosion in the crevice area.
49-61	No corrosion at the scratch area; corrosion pits developing at bottom of crevice.	A few blisters in the film appearing along the scratch; slight corrosion at the scratch; significant corroding at the bottom of the crevice.
69-75	Film intact; no corrosion in the scratch but continuing development of corrosion sites in the crevice area.	A few blisters in the film along the crevice area; slight pitting corrosion of the scratch and severely corroding at the bottom of crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM

Chelating Agent =

1 PHENYL 1, 3-BUTANEDIONE

Conditions =

Concentration = 5% ETOH

Temperature = ambient;

pH =

Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	A1 2024 - T3	A1 7075 - T6
7-20	Paint film intact; with no corrosion at the scratch or crevice areas.	Paint film intact; no corrosion of the scratch or crevice areas.
27-41	Film intact; no corrosion at the scratch; few corrosion sites developing in the crevice area.	Film intact; slight corrosion at the scratch and crevice areas.
49-61	Film intact; no corrosion at the scratch; very few sites continue to develop at the crevice area.	Film remained intact; slight corrosion at the scratch and crevice areas.
69-75	Paint film intact; no corrosion at the scratch; appreciable corrosion at the crevice area.	Paint film still intact; very little corrosion of the scratch; slight corrosion at the crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM
 Chelating Agent = DIPICOLINIC ACID
 Conditions = Concentration = 5% Aqueous
 pH = 12.1 - 10.5
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	Al 2024 - T3	Al 7075 - T6
9	Paint film intact; no corrosion in scratch or crevice areas.	Film intact with no corrosion in scratch or crevice areas.
22-29	Film intact; no corrosion in scratch or crevice areas.	Film intact; very slight corrosion in scratch and crevice areas.
37-44	Film intact; slight pits developing in scratch and crevice areas.	Film intact; significant pitting corrosion developing in scratch and crevice areas.
50-58	Film intact; very slight pitting develops in scratch and crevice areas.	Film intact; significant pitting in scratch area; moderate pitting in crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM

Chelating Agent =

Conditions =

CHELON-DHG

Concentration = 5% Aqueous

pH = 11.91 - 10.67

Temperature = ambient;

Primer Coating = Epoxy

TIME (Days)	TEST EVALUATION	
	A1 2024 - T3	A1 7075 - T6
9	Paint film intact; no corrosion at the scratch or crevice areas.	Film intact; no corrosion in scratch or crevice areas.
22-29	Film intact; no corrosion in scratch or crevice areas.	Film intact; no corrosion in scratch; very slight pits developing in crevice area.
37-44	Film intact; very slight pitting in scratch and crevice areas.	Film intact; slight to moderate pitting in scratch and crevice areas.
50-58	Film intact; slight to less than moderate pitting in scratch area; negligible corrosion in crevice area.	Film intact; moderate corrosion at scratch; somewhat severe corrosion at crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM
 Chelating Agent = CITRIC ACID
 Conditions = Concentration = 5% Aqueous
 pH = 11.9-11.1
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	TEST EVALUATION	
	Al 2024 - T3	Al 7075 - T6
7-20	Paint film intact; no corrosion of the scratch or crevice areas.	A few blisters were appearing on the film; no corrosion in the scratch; a few corrosion sites were developing in the crevice area.
27-41	Paint film substantially O.K.; no corrosion at the scratch; slight corrosion at the crevice area.	Increased blistering; slight corrosion at the scratch and crevice areas.
49-61	Paint film O.K.; no corrosion of the scratch; slight corrosion at the crevice.	Increased film blistering; corrosion in the scratch and at the bottom of the crevice area.
69-75	Paint film O.K.; scratch area not affected by corrosion; significant pitting corrosion of the crevice area.	Film remained blistered over a large area; significant corrosion pitting on the scratch; severely corroded in the crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM

Chelating Agent =

MANDELIC ACID

Conditions =

Concentration = 5% Aqueous

Temperature = ambient;

pH = 11.6-11.05

Primer Coating = Epoxy

TIME (Days)	TEST EVALUATION	
	Al 2024 - T3	Al 7075 - T6
7-20	Paint film not affected; no corrosion at the scratch or crevice areas.	Paint film intact; no corrosion of the scratch or crevice.
27-41	No corrosion at the scratch but some developing potential sites for corrosion in the crevice area.	Some blisters appearing on the paint film; no corrosion in the scratch but a few developing sites for corrosion in the crevice area.
49-61	Paint film intact; slight corrosion in the scratch and moderate corrosion of the crevice areas.	Film intact; some slight to moderate corrosion in the scratch and the crevice areas.
69-75	Film not damaged; slight to moderate corrosion in the scratch and crevice areas.	Paint film essentially O.K.; pitting developing mostly on the bottom of the crevice area with some appreciable pitting at the scratch area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM
 Chelating Agent = ACETYL ACETONE IN ETOH
 Conditions = Concentration = Less than 1%
 pH = Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	Al 2024 - T3	Al 7075 - T6
7-20	Paint film intact; no corrosion of the scratch but one developing site on the crevice.	Paint film intact; no corrosion at the scratch but a potential corrosion site developing in the crevice.
27-41	Paint film intact; no corrosion of the scratch but some development of corrosion sites in the crevice.	Primer film essentially intact; no corrosion at the scratch but potential corrosion sites in the crevice area.
49-61	Paint film showed a few blisters; no corrosion in the scratch but further development of corrosion sites on the crevice area.	Film still O.K. with no corrosion at the scratch; continuing development of corrosion in the crevice.
69-75	Blisters were centered around the crevice area; no corrosion in the scratch and only slightly corroded in crevice area.	Paint film O.K.; slight pitting corrosion on the scratch; considerable pitting corrosion in the crevice areas.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM

Chelating Agent =

BIS(SALICYLALDEHYDE)ETHYLENEDIIMINE

Conditions =

Concentration = Less than 1% in ETOH

Temperature = ambient;

pH =

Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	Al 2024 - T3	Al 7075 - T6
7-20	Paint film intact; scratch and crevice areas not corroded.	Paint film intact; scratch and crevice areas not corroded.
27-41	No corrosion at the scratch area; a few potential corrosion sites developing in the crevice area.	No corrosion at the scratch area; some corrosion sites developing in the crevice area.
49-61	No corrosion at the scratch area; the crevice showed some developing corrosion sites	Blisters on the film near the scratch; mild to slight corrosion noted in the scratch and crevice areas respectively.
69-75	Paint film intact; slight pitting in the scratch area; the bottom portion of the crevice area was significantly corroded.	Paint film blistered; the scratch showed a few corrosion sites; continued development of corrosion in the crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM

Chelating Agent =

Conditions =

CHELON 80

Concentration = 5%, Aqueous

pH = 7.9-9.78

Temperature = ambient;

Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	AL 2024 - T3	AL 7075 - T6
9	Paint film intact; no corrosion at scratch or crevice area.	Film intact - slight corrosion at crevice area.
22-29	Film intact; slight corrosion at scratch and crevice areas.	Film intact; slight corrosion at the scratch and crevice areas.
37-44	Film intact; very slight corrosion in scratch and crevice areas.	Film intact except for a few small blisters with slight to moderate pitting in scratch and moderate to severe in crevice areas.
50-58	Film intact; very slight pitting in scratch area to significant pitting in crevice areas.	Film intact with moderate pitting in scratch area to significant pitting in the crevice areas.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM

Chelating Agent =

SALICYLHYDROXAMIC ACID

Conditions =

Concentration = 2.5% Aqueous
pH = 11.5

Temperature = ambient;

Primer Coating = Epoxy

T E S T E V A L U A T I O N	
TIME (Days)	
	AL 2024 - T3
	AL 7075 - T6
7-13	Paint film intact; no corrosion attack of either the scratch or crevice areas. A few small blisters on the edges; no corrosion in the scratch but a few small pit sites developing in the crevice area.
25-35	Film developed few blisters on the side; no corrosion in the scratch area but developing a few pits at the bottom of the crevice area. There still remained a few small blisters on the film with continued development of the pits in the scratch and crevice areas.
42-49	The blistering of paint film was only slight; very slight pitting in the scratch and some pitting at the bottom of the crevice areas. Paint film blisters remained along the edges; moderate pitting corrosion in both the scratch and crevice areas.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM

Chelating Agent =

ETHYLENEDIAMINETETRAACETIC ACID (EDTA)

Conditions =

Concentration = 5% Aqueous

Temperature = ambient;

pH = 8.4

Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	AL 2024 - T3	AL 7075 - T6
7-13	Paint film intact; no corrosion attack in the scratch or crevice areas.	Paint film intact; a few small pits developing in the scratch and crevice areas.
25-35	Paint film surface slightly blistered; a few small pits developing in the scratch and crevice areas.	Slight blister formation on the paint film; continuing development of a few small corrosion pits in the scratch and crevice areas.
42-49	Significant blistering of the paint film surface; slight to less than moderate corrosion pitting at the scratch and crevice areas respectively.	Small tight blisters were spread over the surface of the film; slight to moderate pitting corrosion in the scratch and crevice areas.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM

Chelating Agent =

Conditions =

DEQUEST 2000

Concentration = 5% Aqueous

pH = 1.1-0.83

Temperature = ambient;

Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	AL 2024 - T3	AL 7075 - T6
7-13	Paint film intact with no corrosion in the scratch or crevice areas.	Primer film intact with no corrosion in the scratch or crevice areas.
25-35	Primer film intact with no corrosion in the scratch or crevice areas.	Film intact with a few pits developing in the scratch and crevice areas.
42-49	Film intact; very little pitting at the scratch and crevice areas.	Film blistered on the edges of the coupon; moderate pitting corrosion at both the scratch and crevice areas.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM
 Chelating Agent = DEQUEST 2006
 Conditions = Concentration = 5% Aqueous
 pH = 11.31-10.93
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	AL 2024 - T3	AL 7075 - T6
7-13	Paint film intact; no corrosion at the scratch; but a few small pits were developing at the crevice.	Paint film intact; a few small pits were developing in the scratch and crevice areas.
25-35	Paint film intact; no corrosion in the scratch but a few small pits continued to develop at the crevice.	Paint film continues intact while the pits continue to develop in the scratch and crevice areas.
42-49	Film still intact; moderate pitting to significant pitting in the scratch and crevice areas respectively.	Film intact; moderate to significantly pitting corrosion continues in the scratch and crevice areas respectively.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM

Chelating Agent =

Conditions =

IMINODIACETIC ACID (IMDA)

Concentration = 5% Aqueous

pH = 8.4

Temperature = ambient;

Primer Coating = Epoxy

TIME (Days)	TEST EVALUATION	
	AL 2024 - T3	AL 7075 - T6
7-13	Paint film intact; no corrosion in the scratch or crevice areas.	Paint film intact; no corrosion in the scratch or crevice areas.
25-35	Paint film intact; no corrosion in the scratch area but some small pits developing in the crevice area.	Paint film slightly blistering some small corrosion pits developing in the scratch or crevice areas.
42-49	Paint film intact; very slight pitting at the scratch and the crevice areas.	Paint film slightly blistered; slight pitting in the scratch and and considerable pitting in the crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM

Chelating Agent =

CHELON 80

Conditions =

Concentration = 5% Aqueous

Temperature = ambient;

pH = 12.2-11.02

Primer Coating = Epoxy

TIME (Days)	TEST EVALUATION	
	AL 2024 - T3	AL 7075 - T6
9	Paint film intact; no corrosion at the scratch or crevice areas.	Paint film intact; no corrosion at the scratch or crevice area.
22-29	Slight blister formation on paint film; a few pit sites developing in the crevice area without any pits in the scratch area.	Paint film intact; a few pits developing in the scratch and crevice areas.
37-44	Film slightly blistered; very slight pitting developing in the scratch and crevice areas.	Film intact; moderate to severe pitting in the scratch and crevice areas.
50-58	Slight blistering of the film; very slight pitting in the scratch and crevice areas.	Paint film o.k.; moderate to severe pitting in the scratch and crevice areas.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM

Chelating Agent =

Conditions =

CHELON 80

Concentration = 5% Aqueous

pH = 12.1

Temperature = ambient;

Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	AL 2024 - T3	AL 7075 - T6
9	Blister formation on the paint film; no corrosion in the scratch or crevice areas.	Paint film intact; a few developing pit sites in the scratch and crevice areas.
22-29	Significant blistering on the paint film; slight corrosion pits in the scratch and crevice areas; (significant corrosion)	Paint film intact; continued development of the pits in the scratch and crevice areas.
37-44	Paint film blistered; slight pitting continuing in the scratch and crevice areas.	Paint film O.K.; severe pitting in the scratch area; moderate pitting at the crevice.
50-58	Several blisters along the crevice edges; slight to moderate pitting in the scratch and crevice area respectively.	Paint film still O.K.; but moderate pitting corrosion of the scratch; severe corrosion of the crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM

Chelating Agent =

Conditions =

Primer Coating = Epoxy

CHELON 120

Concentration = 5% Aqueous

pH = 12.2-11.0

Temperature = ambient;

TIME (Days)	TEST EVALUATION	
	AL 2024 - T3	AL 7075 - T6
9	Paint film intact; no corrosion at the scratch or crevice areas.	Paint film intact with no corrosion at the scratch or crevice areas.
22-29	Film intact; no corrosion at the scratch but some pits forming at the crevice area.	Film intact; a few pit sites developing in the scratch and crevice areas.
37-44	Film still intact; pits developing on the scratch and some corrosion at bottom of crevice area.	Film intact; slight to moderate pitting in the scratch area; severely corroded in the crevice area.
50-58	Paint film intact; moderate corrosion in scratch area to less than moderate in the crevice area.	Film O.K.; slight pitting in the scratch area; severe pitting in the crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM

Chelating Agent =

CHELON 120

Conditions =

Concentration = 10% Aqueous

pH = 11.38-10.93

Temperature = ambient;

Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	AL 2024 - T3	AL 7075 - T6
9	Paint film intact; no corrosion at scratch or crevice areas.	A few blisters in the paint film; no corrosion at scratch or crevice areas.
22-29	Slight film blistering; few small pit sites developing in scratch and crevice areas.	A few small pit sites developing in scratch and crevice areas.
37-44	Slightly increased blistering of paint film; slight pitting in the scratch to a very slight corrosion in crevice area.	Small blisters formed near scratch; slight to moderate pitting in scratch and crevice areas.
50-58	No further development in blisters; slight corrosion in scratch and crevice areas.	The same few blisters remain near the crevice area; moderate corrosion at the crevice to severe corrosion at the scratch area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM
 Chelating Agent = DEQUEST 2010
 Conditions = Concentration = 5% Aqueous
 pH = 0.86-0.92
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	A1 2024 - T3	A1 7075 - T6
8-15	Paint film intact; no corrosion at the scratch or the crevice areas.	Paint film not damaged; potential corrosion sites at the scratch and crevice areas were noted.
29-42	Paint film not damaged; no corrosion of the metal at the scratch or the crevice areas.	Paint film intact; potential corrosion sites continued to develop at the scratch and the crevice areas.
53-141	Slight blister formation of the paint film noted; no corrosion at the scratch area, slight pitting corrosion noted at the crevice area.	Slight blister formation noted on the paint film; slight corrosion at the scratch area; light to moderate corrosion at the crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM
 Chelating Agent = DEQUEST 2044
 Conditions = Concentration = 5% Aqueous
 pH = 7.85-7.86
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	A1 2024 - T3	A1 7075 - T6
8-15	Paint film intact; no corrosion of the metal substrate.	Paint film not damaged; potential corrosion spots noted at the scratch and crevice areas.
29-42	Paint film intact; no corrosion at the scratch or the crevice areas of the substrate.	Paint film intact; potential corrosion sites developing on the scratch and the crevice areas.
53-141	Paint film intact; no corrosion at the scratch area; very light pitting at the bottom of the crevice area.	Paint film intact; potential corrosion sites developing at the scratch area; light pitting at the bottom of the crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM
 Chelating Agent = FYROL-6
 Conditions = Concentration = 5% Aqueous
 pH = 7.54-7.33
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	Al 2024 - T3	Al 7075 - T6
8-15	Paint surface did not start blistering; no corrosion at the scratch or the crevice areas.	Paint film intact; no corrosion at the scratch or the crevice areas.
29-42	Paint film intact; no corrosion of the metal at the scratch or the crevice areas.	No damage to paint film; very, very slight corrosion suspected at the scratch and crevice areas of the metal coupons.
53-141	Paint film intact; no corrosion at the scratch; very light pitting corrosion at the bottom of the crevice area.	Paint film intact; some very light pitting at the scratch area; moderate pitting corrosion at the crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM
 Chelating Agent = DEQUEST 2054
 Conditions = Concentration = 5% Aqueous
 pH = 6.83
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N
	Al 2024-T3 Al 7075-T6
8-15	Paint film intact; no corrosion at the scratch or the crevice areas of the metal substrate.
29-42	Paint film not damaged; no corrosion at the scratch or the crevice areas.
53-141	Paint film not damaged; no corrosion at the scratch area; very light pitting corrosion at the bottom of the crevice area.
	Paint film not damaged; but potential corrosion spots appeared to develop at the crevice and scratch areas.
	Very slight blister formation noted; only potential corrosion sites noted at the scratch and crevice areas.
	Slight blister formation noted; very slight corrosion at the scratch area; moderate pitting corrosion at the crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM
 Chelating Agent = DIPHENYLPHENYLPHOSPHONATE (DPP)
 Conditions = Concentration = 5% in Acetone
 pH = Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	TEST EVALUATION	
	Al 2024-T3	Al 7075-T6
8-15	Paint film intact; no corrosion at either the scratch or the crevice area.	Paint film intact; no corrosion at the scratch or crevice areas.
29-42	No blistering of the paint film; no corrosion of the metal.	No blistering of paint film; only very slight corrosion was suspected at the scratch or crevice area.
53-141	Paint film intact; no blistering; no corrosion at the scratch; some light pitting at the bottom of the crevice area.	Paint film intact; some light pitting at the scratch area; moderate pitting at the bottom of the crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM
 Chelating Agent = FYROL B-M
 Conditions = Concentration = 5% in Methanol
 pH = Temperature = ambient;

Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	Al 2024-T3	Al 7075-T6
8-15	Paint surface intact; no corrosion at scratch or the crevice areas of the metal.	Paint film intact; no corrosion of the metal.
29-42	Paint film intact; no corrosion at either scratch or the crevice area.	Paint film intact; very slight corrosion at the crevice and scratch area suspected.
53-141	Paint film intact; no corrosion at the scratch; some light pitting corrosion at the bottom of the crevice area.	Paint film intact; some light pitting of the scratch area; moderate pitting in the crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM

Chelating Agent =

AMINOBENZOIC ACID

Conditions =

Concentration = 5% Aqueous

Temperature = ambient;

pH = 11.4

Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	Al 2024-T3	Al 7075-T6
4-11	Paint film intact; no corrosion at the scratch or crevice area.	Paint film intact; no corrosion at the scratch or crevice areas.
25-39	Paint surface intact; no corrosion noted at either the scratch or crevice areas.	Paint film intact; slight corrosion at the scratch area and at the crevice area.
50-137	Paint film intact; no corrosion at the scratch or the crevice areas.	Paint surface intact; only slight corrosion at the scratch and crevice areas.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM
 Chelating Agent = HYDANTOIC ACID
 Conditions = Concentration = 5% Aqueous
 pH = 12.0-10.6
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	Al 2024-T3	Al 7075-T6
4-11	Paint film intact; no corrosion at the scratch or the crevice areas.	Paint film is intact; no corrosion at the scratch or the crevice areas.
25-39	Paint surface intact; no corrosion of the scratch or crevice areas.	Paint surface intact; slight corrosion at the scratch; but no corrosion at the crevice areas.
50-137	Paint film intact; light pitting corrosion at the scratch area; slight pitting corrosion at the crevice area.	Paint film intact; no corrosion at the scratch; moderate pitting corrosion in the crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM

Chelating Agent =

O-AMINOPHENOL

Conditions =

Concentration = 5% Aqueous

Temperature = ambient;

pH = 12.0

Primer Coating = Epoxy

TIME (Days)	TEST EVALUATION	
	Al 2024-T3	Al 7075-T6
4-11	Paint film intact; no corrosion at the scratch or the crevice areas.	Paint film intact; no corrosion at the scratch or the crevice areas.
25-39	Paint surface O.K.; no corrosion of the scratch or the crevice areas.	Paint film intact; no corrosion at the scratch or the crevice areas.
50-137	Paint film intact; slight corrosion at the scratch; but no corrosion at the crevice.	Paint intact; no corrosion at the scratch and some light pitting corrosion at the crevice.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM
 Chelating Agent = PICROLONIC ACID
 Conditions = Concentration = 5% Aqueous
 pH = 11.1
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	A1 2024-T3	A1 7075-T6
4-11	Paint intact; no corrosion of the metal at the scratch or crevice areas.	Paint film intact; no corrosion at the scratch or crevice areas.
25-39	Paint film intact; no corrosion at the scratch area; and the crevice area developed a few potential corrosion sites.	Paint film intact; scratch and the crevice areas slight corrosion was noted.
50-137	Paint film intact; the scratch area was slightly pitted; the crevice area developed some slight pitting corrosion.	Paint film intact; slight corrosion at the scratch area; moderate to severe pitting corrosion at the crevice area.

CORROSION PREVENTION CHARACTERISTICS

al = ALUMINUM
 Chelating Agent = GLUTAMIC ACID
 Conditions = Concentration = 5% Aqueous Temperature = ambient;
 pH = 9.15-9.32
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	A1 2024-T3	A1 7075-T6
4-11	Paint film intact; no evidence of corrosion of the scratch or the crevice areas.	Paint film intact; no evidence of corrosion of the scratch or the crevice areas.
25-39	Paint surface intact; no evidence of corrosion of the scratch or the crevice areas.	Paint surface intact; slight corrosion at the scratch and significant corrosion at the crevice areas.
50-137	Paint film still intact; no evidence of corrosion of the scratch; but slight pitting at the bottom of the crevice area.	Paint film intact; a few small pits formed at the scratch; slight to moderate pitting at the bottom of the crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM
 Chelating Agent = GLYCINE
 Conditions = Concentration = 5% Aqueous
 pH = 6.03-6.37
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	A1 2024-T3	A1 7075-T6
4-11	Paint film intact; scratch and crevice areas were free of corrosion.	Paint film intact; scratch and crevice are free of corrosion.
25-39	Paint film intact; no evidence of corrosion either the scratch or crevice areas.	Paint film intact; very slight corrosion was noted at the scratch and crevice areas.
50-137	Film is intact and there is very little evidence of corrosion of the scratch or crevice.	Paint film intact; very little corrosion sites at the scratch area; some moderate pitting corrosion at the bottom of the crevice.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM
 Chelating Agent = GLYCOLIC ACID
 Conditions = Concentration = 5% aqueous
 pH = 2.05-2.28
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N
	Al 2024-T3
	Al 7075-T6
4-11	Paint film intact; no corrosion of the scratch or crevice areas of the coupon.
25-39	Paint film intact; no corrosion of the scratch or crevice.
50-137	Paint film intact; a few small pits had developed on the scratch; some pitting corrosion was noted at the bottom of the crevice areas.
	Paint film intact; no corrosion at the scratch or crevice areas.
	Paint film O.K.; no significant corrosion of the scratch or crevice areas.
	Paint film intact; slight corrosion at the scratch; corrosion pits formed at the bottom of the crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = ALUMINUM

Chelating Agent =

DL-ALANINE

Conditions =

Concentration = 5% Aqueous

pH = 5.68-5.9

Temperature = ambient;

Primer Coating = Epoxy

TIME (Days)	TEST EVALUATION	
	A1 2024-T3	A1 7075-T6
4-11	Paint film intact; no corrosion at scratch or crevice areas.	Paint film intact; no corrosion of the metal.
25-39	Paint film intact; no corrosion of the metal.	Paint film intact; very slight corrosion noted at the scratch and crevice areas.
50-137	Paint film not damaged; no corrosion at the scratch area; a few moderate sized corrosion pits had developed at the crevice area.	Paint film intact; slight corrosion at the scratch area; moderate pitting corrosion at the bottom of the crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM

Chelating Agent =

CHEMRITE

Conditions =

Concentration = 5% Aqueous

Temperature = ambient;

pH = 1.81

Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	CHEMRITE	
1-7	The paint film was intact; no corrosion at either the scratch or crevice areas.	
14-28	Paint film intact; scratch and crevice areas uncorroded.	
28-104	No damage of the paint film; no corrosion of either the scratch or the crevice areas.	

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM

Chelating Agent =

ETHYLENEDIAMINETETRAACETIC ACID (EDTA) AND MALIC ACID

Conditions =

Concentration = 5% Aqueous

Temperature = ambient;

pH = 11.4-10.68 pH = 11.6-11.47

Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	ETHYLENEDIAMINETETRAACETIC ACID (EDTA)	MALIC ACID
7-14	A few small blisters on the backside of the coupon; no corrosion was noted.	Paint film intact; no corrosion was noted.
18-38	Paint film essentially intact; no corrosion of the scratch or crevice area.	Paint film blistering negligible; no corrosion of the scratch or crevice.
44-59	No damage to paint film; scratch crevice areas showed no corrosion.	Very few small blisters on the film; corrosion was observed.
63-84	Very negligible blistering of the film; scratch and crevice are uncorroded.	The paint film is essentially O.K.; scratch and crevice are uncorroded.
98-155	Except for a few small blisters on the back the paint film was O.K.; scratch and crevice remain uncorroded.	Except for the few small blisters the paint film was intact; scratch and crevice remained uncorroded.

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM

Chelating Agent = IMINODIACETIC ACID (IMDA); NITRILOTRIACETIC ACID (NTA)

Conditions = Concentration = 5% Aqueous Temperature = ambient;
pH = 11.5-10.12 pH = 10.2-10.05

Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	IMINODIACETIC ACID (IMDA)	NITRILOTRIACETIC ACID (NTA)
7-14	Paint film intact; no corrosion of either scratch or crevice area.	Film intact; no corrosion of scratch or crevice area.
18-38	No corrosion of scratch or crevice area.	No corrosion of the scratch or crevice area noted.
44-59	Film essentially intact except for a few small blisters in back; no corrosion of the scratch or crevice area.	No corrosion of the scratch or crevice area.
63-84	Paint film is O.K.; no corrosion.	Paint film O.K.; no corrosion.
98-155	Paint film intact; no corrosion at the scratch or crevice area.	Paint film intact; no corrosion of the scratch or crevice area observed.

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM
 Chelating Agent = dl-ALANINE AND CHELON DHG
 Conditions = Concentration = 5% Aqueous
 pH = 5.65 12.0-11.7
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	TEST EVALUATION	
	dl-ALANINE	CHELON-DHG
8-14	Paint film blistering along the edge of coupon; scratch and the crevice areas are not corroded.	Film is intact; scratch and the crevice are not corroded.
22-36	Blister pattern is confined to the front of the coupon; scratch and crevice areas are not corroded.	Very few blisters appeared on the film; scratch and crevice are corrosion free.
36-112	Film blistering diminished; major areas of the paint film remains in good condition; scratch and crevice are not corroded.	Film is substantially intact; as the blisters developed very little beyond their first stage; scratch and crevice are still free of corrosion.

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM
 Chelating Agent = SULPHOSALICYLIC ACID AND MALIC ACID
 Conditions = Concentration = pH = 1.0 pH = 1.85-1.90
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	SULFOSALICYLIC ACID	MALIC ACID
8-14	Tiny blisters appear on the film around the edges of the coupon; no corrosion in the scratch or crevice areas.	The usual pattern of blisters has appeared on the coupon; no corrosion in the scratch or the crevice areas.
22-36	Blister pattern is concentrated around the holes on the coupon; no corrosion on the scratch or the crevice.	Blister area is concentrated around the holes; no corrosion on the scratch or crevice.
36-112	Blister pattern did not develop any further and the film is substantially in very good condition; no corrosion of the scratch or crevice.	Blisters are unchanged; film is substantially undamaged; scratch and crevice areas remain uncorroded.

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM
 Chelating Agent = DEQUEST 2054 AND DEQUEST 2044
 Conditions = Concentration = 5% Aqueous Temperature = ambient;
 pH = 6.9-6.85 7.9-7.82
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	DEQUEST 2054	DEQUEST 2044
7-14	Slight blistering of the paint; no corrosion of the scratch or crevice area.	Slight blisters of the paint film; no corrosion of the scratch or crevice areas.
20-31	No corrosion of the scratch or crevice areas.	Increased film blistering; no corrosion of the scratch or crevice areas.
44-59	Film blistering around crevice; no corrosion of the scratch or the crevice areas.	No corrosion at the scratch or crevice.
64-79	No significant corrosion at the scratch or crevice.	No increase in film blistering; no corrosion of the scratch or crevice.
86-101	Paint film blistering around the crevice; scratch and crevice was not corroded.	Blisters around the crevice; scratch and crevice not corroded.

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM
 Chelating Agent = CHEMRITE
 Conditions = Concentration = 5% Aqueous
 pH = 1.81
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	CHEMRITE	
7-14	A few blisters on the surface of the film; no corrosion of the scratch or crevice areas.	
20-31	Some blistering of the film; but no corrosion at the scratch and crevice areas.	
44-59	Blisters on the paint film around the crevice; the scratch and crevice are uncorroded.	
64-79	Film blisters around the crevice and scratch; the scratch and crevice not corroded.	
86-101	Paint film blistering around the scratch and crevice areas; very slight corrosion at the scratch; no corrosion at the crevice.	

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM
 Chelating Agent = CHELON DHG AND DEQUEST 2010
 Conditions = Concentration = 5% Aqueous Temperature = ambient;
 pH = 12.08-11.72 pH = 1.2-1.11
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	CHELON DHG	DEQUEST 2010
7-14	Paint film severely blistered; no corrosion of the scratch or crevice areas.	Paint film intact; no corrosion of the scratch or crevice areas.
20-31	No corrosion of the scratch or crevice areas.	Film free of blisters; no corrosion of the scratch or crevice areas.
44-59	No corrosion at the scratch or crevice areas.	Paint film is intact; no corrosion of the scratch or crevice areas.
64-79	No corrosion of the scratch or crevice areas.	Film intact; no corrosion of the scratch or crevice areas.
86-101	Paint film damaged due to severe blistering all over the surface; no significant corrosion of the scratch or the crevice areas.	Paint film intact; very slight pit formation at the scratch; but no corrosion at the crevice area.

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM
 Chelating Agent = CHELON 120 AND CHELON 80
 Conditions = Concentration = 5% aqueous Temperature = ambient;
 pH = 12.18-12.08 pH = 12.03-11.9
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	CHELON 120	CHELON 80
7-14	Paint film severely blistered; but no corrosion of the scratch or crevice.	Paint film badly blistered; no corrosion at the scratch and crevice areas.
20-31	The scratch and crevice not uncorroded.	The scratch and crevice not uncorroded.
44-59	The scratch and crevice not corroded; increased film blistering.	The scratch and crevice not corroded; increased blistering.
64-79	The scratch and crevice areas not corroded.	No corrosion at the scratch and crevice are uncorroded.
66-101	Severe blistering all over surface of the film; but the scratch and crevice areas showed no corrosion.	The surface of the film was badly blistered; but the scratch and crevice areas showed no corrosion damage.

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM
 Chelating Agent = DEQUEST 2006 AND DEQUEST 2000
 Conditions = Concentration = 5% Aqueous
 pH = 11.35-11.25 pH = 1.15-1.19
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	DEQUEST 2006	DEQUEST 2000
7-14	A few blisters in the paint film; scratch and crevice uncorroded.	Very slight film blistering; scratch and crevice uncorroded.
20-31	No corrosion of scratch or crevice.	No increase in No. of blisters; no corrosion at scratch or crevice areas.
44-59	No corrosion of scratch or crevice areas.	Very little additional blistering and no corrosion in the scratch or crevice.
64-79	No change in the blister pattern; no corrosion of scratch or crevice areas.	No corrosion of scratch or crevice.
86-101	Significant blistering over the coupon; no corrosion of scratch or crevice areas.	Paint film essentially intact; no corrosion of scratch or crevice areas.

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM
 Chelating Agent = DEQUEST 2054 AND DEQUEST 2006
 Conditions = Concentration = 5% Aqueous Temperature = ambient;
 pH = 6.80-6.87 pH = 11.14-11.15
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	DEQUEST 2054	DEQUEST 2006
1-7	Very slight blistering of the paint film; scratch and crevice areas not corroded.	Very little blistering of the paint film; no corrosion at the scratch and crevice areas.
14-28	Paint film blistering only around crevice; no corrosion at scratch and crevice areas.	Slight blistering of the film around the crevice; the scratch and the crevice free of corrosion.
28-104	No significant damage to the paint film; no corrosion at the scratch or crevice areas.	No increase of film blistering; no corrosion at the scratch or crevice areas.

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM
 Chelating Agent = MANDELIC ACID AND IMINODIACETIC ACID
 Conditions = Concentration = 5% Aqueous Temperature = ambient;
 pH = 1.94 pH = 10.6-9.98
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	MANDELIC ACID	IMINODIACETIC ACID
8-14	Blisters appear on the paint film around the edges of the metal; scratch and crevice areas are uncorroded.	Film blisters appear around the edges of the coupon; scratch and crevice have no corrosion.
22-36	Film blisters persist; scratch and crevice areas have no corrosion.	Blisters are very small in their pattern around the holes; scratch and crevice are uncorroded.
36-112	Blisters did not increase any further leaving the majority of the film area in good condition; scratch and crevice have no corrosion.	Blisters remain in their original condition with major film area nearly intact; scratch and crevice showed no corrosion.

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM
 Chelating Agent = DEQUEST 2010 AND DEQUEST 2000
 Conditions = Concentration = 5% Aqueous Temperature = ambient;
 pH = 1.23-1.13 pH = 1.0
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	DEQUEST 2010	DEQUEST 2000
8-14	Very few blisters on the paint film; scratch and crevice were uncorroded.	Few blisters on the film; scratch and crevice were not corroded.
22-36	Fewer blisters noted; paint film essentially intact; no corrosion of the scratch or crevice.	Very few blisters around the holes; no corrosion of the scratch or crevice.
36-112	Paint film essentially intact; no corrosion of the scratch and crevice areas.	Paint film intact except for the few blisters around the holes, also the skin lifted off the surface near scratch; no corrosion of the metal underneath; scratch and crevice are free of corrosion.

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM
 Chelating Agent = GLYCOLIC ACID AND GLYCINE
 Conditions = Concentration = 5% Aqueous Temperature = ambient;
 pH = 1.93-1.78 pH = 5.9-5.8
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	GLYCOLIC ACID	GLYCINE
8-14	Paint film is intact; no evidence of blistering; scratch and crevice were free of corrosion.	Film was essentially intact except for slight blistering; scratch and crevice were uncorroded.
22-36	Film remained intact; no evidence of blistering; scratch and crevice continue to remain free of corrosion.	A few blisters around the holes; no corrosion of the scratch or crevice areas.
36-112	Film intact with no evidence of blisters; scratch and crevice were free of corrosion.	Film was essentially intact with very little evidence of blistering; no corrosion of the scratch or crevice areas.

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM
 Chelating Agent = CHELON 80 AND CHELON 120
 Conditions = Concentration = 5% Aqueous
 pH = 11.86-11.80 pH = 11.90-11.68
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	CHELON 80	CHELON 120
1-7	Very slight blistering of the paint film; no corrosion of the scratch or crevice.	Slight blistering of the film; no corrosion of the scratch or crevice.
14-28	Very few blisters; no corrosion of the scratch or crevice.	Paint film essentially intact; scratch and crevice areas not corroded.
23-104	No enlargement of film blistering; no corrosion underneath film; scratch and crevice areas not corroded.	Paint film essentially intact; no corrosion at the scratch and crevice areas.

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM

Chelating Agent = p-AMINOBENZOIC ACID AND DIPHENYL PHENYL PHOSPHONATE

Conditions = Concentration = 5% in Acetone; Temperature = ambient;
pH = 11.8-11.6

Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	p-AMINOBENZOIC ACID	DIPHENYL PHENYL PHOSPHONATE
8 14	Very few blisters on the paint film; no corrosion of the scratch or crevice areas.	A few blisters on the film; no corrosion of the scratch or crevice areas.
22-36	Very slight blistering of paint film; no corrosion of the scratch or the crevice.	Film blisters around the outside edge of the crevice; scratch and crevice remain free of corrosion.
36-112	The scratch and the crevice are free from corrosion; no increase in paint film damage.	No damage to paint film; scratch and crevice remain free of corrosion.

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM

Chelating Agent =

DL-GLUTAMIC ACID AND HYDANTOIC ACID

Conditions =

Concentration = 5% Aqueous

Temperature = ambient;

pH = 9.1-9.2

pH = 11.8-11.6

Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	DL-GLUTAMIC ACID	HYDANTOIC ACID
8-14	A few blisters on the paint film; no corrosion of the scratch or crevice.	Very slight blistering of the film; scratch and crevice free from corrosion.
22-36	No increase in blisters; no corrosion at the scratch or crevice areas.	Slight blistering only; scratch and crevice free from corrosion.
36-112	No further development of the small blisters; scratch and crevice areas still free of corrosion.	Film blisters did not increase; no corrosion of the scratch or the crevice or underneath the blisters.

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM
 Chelating Agent = FYROL 6 AND FYROL-BIS BETA
 Conditions = Concentration = 5% in Methanol
 pH = 7.86-7.3
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	FYROL 6	FYROL-BIS BETA
8-14	Paint film intact; no corrosion of the scratch or crevice areas.	Paint film intact; no corrosion of scratch or the crevice.
22-36	A few blisters noted around the hole; no corrosion of the scratch or crevice.	Very few blisters appearing around the hole; no corrosion of the scratch or crevice.
36-112	No further increase of film blistering; no evidence of corrosion of the metal underneath; scratch and crevice uncorroded.	Blisters didn't develop any further; no corrosion of the scratch or crevice areas.

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM
 Chelating Agent = SULFOSALICYLIC ACID AND MANDELIC ACID
 Conditions = Concentration = 5% Aqueous Temperature = ambient;
 pH = 11.55 pH = 11.6-10.82
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	SULFOSALICYLIC ACID	MANDELIC ACID
7-14	Slight blistering of the paint film; no corrosion of the scratch or crevice areas.	Slight blistering of paint film; no corrosion at the scratch and crevice areas.
18-38	No corrosion of the scratch or crevice areas.	Scratch and crevice areas not corroded.
44-59	Increased blistering; scratch and crevice not corroded.	No corrosion at the scratch and crevice areas.
63-84	Scratch and crevice remain uncorroded.	Increase in blisters around the crevice; no corrosion at the scratch and crevice.
98-174	Paint film not damaged except for the few small blisters; scratch and crevice showed no corrosion.	The paint film was essentially intact with the exception of a very few small blisters; scratch and crevice areas showed no significant corrosion.

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM
 Chelating Agent = PYROCATECHOL AND MALEIC ACID
 Conditions = Concentration = 5% Aqueous Temperature = ambient;
 pH = 7.9-7.8 pH=5.6-5.7
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	PYROCATECHOL	MALEIC ACID
7-23	Paint film intact; there was no corrosion of the metal.	Paint film intact; there was no corrosion of the scratch or the crevice areas of the metal.
23-108	Paint film intact; there is no corrosion of the metal.	Paint film intact; no corrosion of the metal.

CORROSION PREVENTION CHARACTERISTICS

Metal = TITANIUM
 Chelating Agent = MALONIC ACID AND ANTHRANILIC ACID
 Conditions = Concentration = 5% Aqueous Temperature = ambient;
 pH = 1.56-1.49 pH = 11.6-11.35
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	MALONIC ACID	ANTHRANILIC ACID
7-23	A few blisters around the crevice; no corrosion of the metal.	Paint film was intact; no corrosion of the scratch or the crevice areas.
23-108	Slight blistering of the paint film; no corrosion of the metal.	No corrosion of the scratch or crevice areas except for very slight blistering.

CORROSION PREVENTION CHARACTERISTICS

Metal = STAINLESS STEEL

Chelating Agent =

FYROL BIS BETA AND FYROL-6

Conditions =

Concentration = 5% in Methanol

Temperature = ambient;

pH = 5% in H₂O 7.56-7.3

Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	FYROL BIS BETA (MeOH)	FYROL - 6 (H ₂ O)
4-11	Paint surface showed small blisters over a large area; no corrosion of the scratch or crevice area.	Blistering of the paint surface around the crevice and scratch area; no corrosion at the scratch or crevice areas.
25-39	The blisters had increased in size and covered a larger area; the scratch and crevice are free from corrosion.	Increased blistering of the film; the scratch and the crevice were not corroding.
50-137	The blisters remained on the paint surface; when the film dried the blister tended to disappear; the scratch and crevice were free from corrosion.	Paint surface was not damaged much; no corrosion of the metal at the scratch and crevice areas.

Metal = STAINLESS STEEL
Chelating Agent = DIPHENYL PHENYL PHOSPHONATE (DPP)
Conditions = Concentration = 5% in Acetone Temperature = ambient;
pH =
Primer Coating = Epoxy

TIME (Days)	TEST EVALUATION
	DIPHENYL PHENYL PHOSPHONATE (DPP)
4-11	A few blisters were formed on the paint surface; the scratch and crevice areas were free from corrosion.
25-39	Increased blistering of the paint film noted; no corrosion of the metal.
50-137	Significant blistering of the paint film; but no corrosion at the scratch and the crevice areas.

CORROSION PREVENTION CHARACTERISTICS

Metal = STAINLESS STEEL
 Chelating Agent = MANDELIC ACID AND IMINODIACETIC ACID (DISODIUM SALT)
 Conditions = Concentration = 5% Aqueous Temperature = ambient;
 pH = 1.83-2.0 pH = 10.6-10.16
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	MANDELIC ACID	IMINODIACETIC ACID
8-16	Paint film blistered around the scratch and crevice area; no corrosion of the metal.	Blistering of the paint film near the scratch and crevice area; no corrosion of the metal.
22-44	Slight blistering of the paint film on both sides of the metal coupon; no corrosion of the metal.	Paint film blistering continued; the scratch and crevice area is not corroded.
52-66	The blistering pattern on the film remained unchanged; the scratch and crevice not corroded.	The slight blistering pattern remained unchanged; scratch and crevice showed no corrosion.
80-156	The film did not deteriorate further; the scratch and the crevice areas remained uncorroded.	The film did not deteriorate any more than above; the scratch and crevice were not corroded.

CORROSION PREVENTION CHARACTERISTICS

Metal = STAINLESS STEEL
 Chelating Agent = SULFOSALICYLIC ACID AND MALIC ACID
 Conditions = Concentration = 5% Aqueous Temperature = ambient;
 pH = 0.8-0.95 pH = 1.8-1.9
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	SULFOSALICYLIC ACID	MALIC ACID
8-16	Paint film blistered; no corrosion at the scratch and crevice areas.	Film blistered along the edges; no corrosion of the scratch or crevice areas.
22-44	Significant blistering of the paint film; no corrosion of the crevice and scratch area.	Slight blistering along the edges of the coupon; no corrosion at the scratch and crevice areas.
52-66	No corrosion of the metal except for the blistering of the paint film.	The slight blistering of the film remained; scratch and crevice continued to remain uncorroded.
80-156	Paint film blistered with slight damage to the paint film; no corrosion of the metal substrate.	No corrosion of the metal except for slight deterioration of the paint film.

CORROSION PREVENTION CHARACTERISTICS

Metal = STAINLESS STEEL
 Chelating Agent = DEQUEST 2044
 Conditions = Concentration = 5% Aqueous
 pH = 7.85 - 7.93
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N
	Stainless Steel
7-14	Slight blistering of the paint film; the scratch and crevice areas of the metal unaffected.
21-35	Slight blistering of the paint film; the scratch and crevice areas were corroded.
42-63	Increased blistering of the paint film; scratch and crevice areas uncorroded.
70-78	Paint film damage on both sides of the coupon; scratch and crevice area uncorroded.

CORROSION PREVENTION CHARACTERISTICS

Metal = STAINLESS STEEL
 Chelating Agent = DEQUEST 2006 AND DEQUEST 2054
 Conditions = Concentration = Temperature = ambient;
 pH = 11.35-11.15 6.83-6.95
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	ALKALINE-PRE-CLEANING	ACID PRE-CLEANING
7-14	Slight blistering of the film; no corrosion of the metal	Paint film showed a few blisters along edges; scratch and crevice areas were uncorroded.
21-35	Increased blistering of the paint film; no corrosion of the metal.	Increased blistering of the paint film; no corrosion of the metal coupons
42-63	Blistering remained unchanged on both sides of coupon; scratch and crevice areas were uncorroded.	Blistering remained unchanged; scratch and crevice areas were uncorroded.
70-78	Significant paint film lifting on both sides of the coupon; scratch and crevice areas were uncorroded.	Paint film damage noted on both sides of the coupon; scratch and crevice areas of the metal remained uncorroded.

CORROSION PREVENTION CHARACTERISTICS

Metal = STAINLESS STEEL
 Chelating Agent = DEQUEST 2010 AND DEQUEST 2000
 Conditions = Concentration = 5% Aqueous
 pH = 0.86-0.83 1.15-0.83
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	DEQUEST 2010	DEQUEST 2000
7-14	Small blisters on the film; no corrosion of the metal.	A few small blisters on the film; no corrosion at the scratch or crevice areas of the metal.
21-35	Slight increase in the film blistering; no corrosion of the metal.	Paint film blistering increased; scratch and crevice areas uncorroded.
42-63	Film blisters remained over a large area; no corrosion of the metal.	Film blisters on both sides of the coupon; the scratch and crevice areas are uncorroded.
70-78	Paint film blistered on both sides of the coupon over a large area; no corrosion at the scratch or the crevice areas of the coupon.	The blisters remained unchanged; the scratch and crevice were uncorroded.

CORROSION PREVENTION CHARACTERISTICS

Metal = STAINLESS STEEL
 Chelating Agent = CHELON 80
 Conditions = Concentration = 5% Aqueous Temperature = ambient;
 pH = 12.0-8.3 pH = 12.0-11.5
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	ACID PRE-CLEANING	ALKALINE PRE-CLEANING
7-14	Slight blistering of the film; no corrosion at the scratch or crevice areas.	Slight blistering of the paint film along the edges; no corrosion of the metal.
21-35	Paint film blisters increased; no corrosion.	Paint film blisters cover larger area; no corrosion at the scratch or crevice areas.
42-63	The blisters cover a larger area; no corrosion of the metal.	The blisters remain; no corrosion at the scratch or crevice areas.
70-78	Paint film blisters are noticed on both sides; no corrosion at the scratch or crevice areas.	The blisters are noticed over large areas on both sides of the coupon; no corrosion at the scratch or crevice areas.

CORROSION PREVENTION CHARACTERISTICS

Metal = STAINLESS STEEL
 Chelating Agent = CHELON - DHG
 Conditions = Concentration = 5% Aqueous
 pH = 12.0-9.9 pH = 12.0-11.4
 Temperature = ambient;
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	ACID PRE-CLEANING	ALKALINE PRE-CLEANING
7-14	Blistering of the paint film noted around the crevice area; no corrosion of the metal.	A few blisters in primer film with no corrosion of the metal.
21-35	Slight increase in film blistering; no corrosion of the metal.	Slight increase in the blistering of the paint film; no corrosion of the film.
42-63	Paint film blisters spread out to other areas; no corrosion of the metal.	Film blisters spread over a larger area; no corrosion at the scratch or crevice areas.
70-78	Increased blistering of the paint film; no corrosion at the scratch or crevice areas.	Paint film blisters on both sides of the coupon; no corrosion of scratch or crevice.

CORROSION PREVENTION CHARACTERISTICS

Metal = STAINLESS STEEL
 Chelating Agent = CHELON 120
 Conditions = Concentration = 5% Aqueous Temperature = ambient;
 pH = 12.0-8.3 pH = 12.0-11.7
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	ACID PRE-CLEANING	ALKALINE PRE-CLEANING
7-14	Slight damage to the paint film through blistering; no corrosion of the metal.	A few small blisters on the film; no corrosion at the scratch or crevice areas.
21-35	No increase in blistering; no corrosion.	Slightly increased blistering; no corrosion at the scratch or crevice areas.
42-63	Only slight damage of the paint film; no corrosion of the metal.	Significant blistering noted; but no corrosion.
70-78	Paint film damage did not indicate an increase; no corrosion at the scratch or crevice areas or underneath the blisters.	Paint film blistering on both sides of the coupon; no corrosion of the metal.

CORROSION PREVENTION CHARACTERISTICS

Metal = STAINLESS STEEL

Chelating Agent =

GLYCOLIC ACID AND GLYCINE

Conditions =

Concentration = 5% Aqueous

Temperature = ambient;

pH = 1.9

pH = 5.2 - 5.5

Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	GLYCOLIC ACID	GLYCINE
7-23	The paint film is intact; no corrosion of the metal.	Tiny blisters on the paint film around the crevice areas of the coupon; no corrosion of the metal noted.
23-108	Film blisters on the front and back of the coupon; no corrosion of the metal.	Several blistering noted; no corrosion of the scratch or the crevice areas.

CORROSION PREVENTION CHARACTERISTICS

Metal = STAINLESS STEEL

Chelating Agent = DL-ALANINE AND DL-GLUTAMIC ACID

Conditions = Concentration = 5% Aqueous

pH = 5.6-5.5 pH = 9.4-9.5

Temperature = ambient;

Primer Coating = Epoxy

TIME (Days)	TEST EVALUATION	
	DL-ALANINE	DL-GLUTAMIC ACID
7-23	Tiny blisters around the crevice in the metal coupon; no corrosion of the scratch or the crevice areas.	Very few blisters formed around the crevice areas; no corrosion of the metal at the scratch or the crevice areas.
23-108	Film blisters persisted; no corrosion of the metal	Film blisters persist; no corrosion of the metal at the scratch or the crevice areas.

CORROSION PREVENTION CHARACTERISTICS

Metal = STAINLESS STEEL
 Chelating Agent = SALICYLHYDROXAMIC ACID AND NITRILOTRIACETIC ACID
 Conditions = Concentration = 5% Aqueous Temperature = ambient;
 pH = 11.6-10.6 pH = 9.14-9.17
 Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	SALICYLHYDROXAMIC ACID	NITRILOTRIACETIC ACID
7-23	Paint film intact; no corrosion of the metal either at the scratch or crevice areas.	Paint film blistering noted; but no corrosion of the metal at the scratch or the crevice areas.
23-108	Blisters appearing both front and back on the paint film; no corrosion of the metal.	Very few blisters in both front and back side of the coupon; no corrosion of the metal at scratch or the crevice areas or underneath the blisters.

CORROSION PREVENTION CHARACTERISTICS

Metal = STAINLESS STEEL

Chelating Agent =

PYROCATECHOL AND MALONIC ACID

Conditions =

Concentration = 5% Aqueous

Temperature = ambient;

pH = 8.14-8.05 pH = 1.60-1.68

Primer Coating = Epoxy

TIME (Days)	T E S T E V A L U A T I O N	
	PYROCATECHOL	MALONIC ACID
7-23	Paint film blistered; no corrosion of the metal.	Paint film blistered; no corrosion of the scratch on the crevice areas.
23-108	Severe blistering of the film throughout the surface; no corrosion of the scratch or the crevice areas.	Considerable blistering of this paint film; but no corrosion of the scratch or the crevice areas.

CORROSION PREVENTION CHARACTERISTICS

Metal = STAINLESS STEEL
 Chelating Agent = MALEIC ACID AND ANTHRANILIC ACID
 Conditions = Concentration = 5% Aqueous
 pH = 11.6-11.58 pH = 12.15-12.18
 Primer Coating = Epoxy
 Temperature = ambient;

TIME (Days)	T E S T E V A L U A T I O N	
	MALEIC ACID	ANTHRANILIC ACID
7-23	Blister formed over a large area of paint film; no corrosion of the metal.	Paint film blistered over a large area; no corrosion of the metal.
23-108	Except for the blistering of the paint film there was no corrosion.	Except for the blistering of the paint film; no corrosion of the scratch or the crevice areas of the metal.