204
8-30 C
RFP-1891

2252
RFP-1891
August 7, 1972

THIS DOCUMENT CONFIRMED AS
UNCLASSIFIED
DIVISION OF CLASSIFICATION
BY GH Kahn/amb
DATE 9/7/72

THE CORROSION AND STRESS-CORROSION CRACKING
OF PAINTED U-4.2 wt% Nb

James M. Macki
Robert L. Kochen

DOW CHEMICAL U.S.A.
ROCKY FLATS DIVISION
P. O. BOX 888
GOLDEN, COLORADO 80401

U. S. ATOMIC ENERGY COMMISSION
CONTRACT AT(29-1)-1106

26448

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LEGAL NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Printed in the United States of America
Available from the
National Technical Information Service
U. S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.95

Printed
August 7, 1972

RFP-1891
UC-25 METALS, CERAMICS
AND MATERIALS
TID-4500 - 56th Ed.

THE CORROSION AND STRESS-CORROSION CRACKING
OF PAINTED U-4.2 wt% Nb

James M. Macki
Robert L. Kochen

KWIC Index:

U-Nb Alloys
Stress-Corrosion Cracking
Paint Coatings
Organic Coatings

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

DOW CHEMICAL U.S.A.
ROCKY FLATS DIVISION
P. O. BOX 888
GOLDEN, COLORADO 80401

Prepared under Contract AT(29-1)-1106
for the
Albuquerque Operations Office
U. S. Atomic Energy Commission

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

RFP-1891

CONTENTS

Abstract	1
Introduction	1
Experimental	1
Salt Spray Test	1
Stressed C-ring Test	2
Results and Discussion	3
Conclusions	6
References	7

ACKNOWLEDGMENTS

The authors acknowledge J. F. Boland and the Rocky Flats Fabrication Research and Development Group for providing the necessary specimens. R. L. Riegel is acknowledged for selecting and applying the paint coatings and J. E. Snyder is acknowledged for the metallography.

THE CORROSION AND STRESS-CORROSION CRACKING OF PAINTED U-4.2 wt% Nb

James M. Macki and Robert L. Kochen

Abstract. Salt spray (fog) and stress-corrosion cracking (SCC) tests were conducted on painted U-4.2 wt% Nb alloy specimens. The paint coating consisted of an epoxy primer with a polyurethane cover coat. The primer and cover coat were applied by spraying. The test results showed that the alloy was protected, but not completely, from corrosion in the 3.5 wt% NaCl salt fog environment. The C-ring SCC tests showed that the paint system would not effectively protect the substrate metal from SCC in an aqueous chloride environment because the C-rings failed at flaws in the paint coating.

INTRODUCTION

The aged U-4.2 wt% Nb alloy has some applications in which it will be exposed to the atmosphere. Since this alloy is susceptible to stress-corrosion cracking (SCC), protective coatings are required. This report summarizes tests that were conducted at Rocky Flats to evaluate the protective properties of a paint system on the aged U-4.2 wt% Nb alloy.

For this investigation, back-extruded cylinders of U-4.2 wt% Nb were solutionized at 850°C, quenched, and aged 80 hours at 260°C. This produced equi-axed grains having the alpha structure. The alpha structure is a monoclinic transition phase which can contain 3.7 to 6.9 wt% Nb in a supersaturated solid solution. The aged material exhibits an average 0.2% offset yield strength of 180,000 psi; an average yield strength of 180,000 psi; an average ultimate tensile strength of 200,000 psi; an average elongation of 6%; and an average elastic modulus of 18.3×10^6 psi.¹ Typical specifications for the solution-quenched and the age-hardened alloy are listed in Table 1.²

Table 1. Typical Specifications for the U-4.2 wt% Nb Alloy.*

Property	Solution-Quenched	Aged 80 Hours at 260°C
Yield strength (0.2% offset)	46,000 psi	175,000 psi
Tensile strength	150,000 psi	190,000 psi
Elastic modulus	12×10^6 psi	18×10^6 psi
Reduction of area	25%	4%
Elongation	23%	4%
Hardness	R _A 65	R _A 75
Impact strength	—	4.5 ft-lb
Density	17.9 ± 0.2 g/cm ³	18.0 ± 0.2 g/cm ³

*USAEC RFP-1703.

The U-Mo and U-Nb binary alloys, and the ternary U-7.5 wt% Nb-2.5 wt% Zr alloy are known to be susceptible to SCC.³⁻¹¹ A recent investigation at Rocky Flats¹¹ disclosed that the aged (80 hours at 260°C) U-4.2 wt% Nb alloy is susceptible to SCC when stressed in environments containing moisture, oxygen, and chloride ions. In the Rocky Flats study, smooth, dead-weight loaded, static tensile SCC specimens failed, under an applied stress of 20,000 psi, by an intergranular SCC mode in oxygen-saturated water containing 50-ppm chloride ions. Smooth, constant deflection, four-point bend SCC specimens also failed by the intergranular SCC mode in the same aqueous environment.

This investigation was conducted to evaluate the protective properties of the paint system and to determine whether the paint coating would protect the U-4.2 wt% Nb alloy from SCC in aqueous chloride environments. The paint system that was tested consisted of Chem Glaze 9922® yellow epoxy primer and a Urethane Z051® clear-polyurethane cover coat. Both the primer and the cover coat are manufactured by the Hughson Chemical Company of Erie, Pennsylvania.

EXPERIMENTAL

Two types of tests were conducted to evaluate the corrosion protection provided by the paint coating: A salt spray (fog) test was used to evaluate the corrosion protection and stressed C-ring tests were used to evaluate the SCC protection.

Salt Spray Test

Evaluating the protective properties of a paint system by exposure to a marine (sea coast) atmosphere or to some other atmospheric environment would require several years of testing. Accordingly, the salt spray (fog) test has been designated by the ASTM as a suitable accelerated test for evaluating corrosion resistant coatings.¹² This ASTM test was selected to evaluate the corrosion protection provided by the paint system proposed for use on the aged U-4.2 wt% Nb alloy.

Specimens for the salt fog and SCC tests were obtained from a back-extruded cylinder of the aged U-4.2 wt% Nb alloy.

The cylinder had a 6-in.-outside diameter and a ¼-in.-wall thickness. One-inch-wide circular rings were machined from the cylinder. A 3-in.-long section of each ring was cut out and used for the salt fog tests. The remainder of the ring, which was shaped like the letter C, was used for the SCC tests. Only a 6-in. length of cylinder was available for the tests so there were six salt spray (fog) specimens and six SCC specimens. The sixth SCC specimen was not tested.

A ¼-in. diameter hole was drilled through each salt fog specimen; a cylindrical silicone rubber gasket and a 3-in. length of 19-gage stainless steel (type 347 welding rod) wire was inserted into each hole as a hanger support. The silicone gasket eliminated galvanic effects between the hanger and specimen.

The six salt spray (fog) specimens and three C-ring SCC specimens were spray painted with a paint system consisting of an epoxy primer (Chem Glaze 9922) and a polyurethane cover coat (Urethane Z051).

The epoxy primer was mixed five parts of Chem Glaze 9922-A to one part of 9922-B by volume. This mixture was then thinned (5 parts primer to 1 part xylene by volume) for use in a standard air spray gun. After application, the epoxy mixture was allowed to cure for 24 hours. The epoxy coating averaged 0.003-in. thick.

The polyurethane cover coat was also applied by spraying and was allowed to cure for 7 days before any tests were conducted with the painted specimens. The cover coat averaged 0.002-in. thick. The polyurethane formed a hard film over the epoxy primer and thereby provided protection against mechanical abrasion.

The painted specimens were prepared and tested in conformity with ASTM Designation B117-64.¹² After being washed with distilled water, the coating on each specimen was intentionally damaged by a controlled score mark to shorten the test by reducing the time required for a natural breakdown of the coating. A scribing tool, ground to a single point, was used to score each specimen. Each sample was scored near its center with the scribing tool held perpendicular to the specimen surface. The score mark began at a point ½ in. from the end, and continued to a point ½ in. from the opposite end. A flexible straight edge was used to guide the scribing tool in a straight line. The 2-in.-long score mark penetrated completely through the coating and into the substrate metal to produce a uniformly bright line.

The exposure tests were conducted in the salt spray cabinet with a single Uni-Fog® dispersion tower (manufactured by the G. S. Equipment Company of Cleveland, Ohio). This

cabinet conforms to ASTM Designations B117,¹² B287,¹³ and B386.¹⁴ The dispersion tower is designed to distribute the salt solution as a fog uniformly throughout the chamber. Each specimen was independently suspended from its stainless steel wire hanger. Because of their curved surfaces, the specimens hung 15 to 30 degrees from vertical. The specimens were placed inside the salt spray chamber so that they were perpendicular to the flow of fog through the chamber. The chamber was maintained at $50 \pm 1^\circ\text{C}$ during the tests.

A filtered compressed air supply of 10 psig was used to atomize the test solution containing 35 g/l of technical grade sodium chloride and tap water.

The salt spray (fog) test was a continuous 90-day test except for short interruptions to inspect the specimens.

After 90 days of exposure to the salt fog, the specimens were removed and the coatings were evaluated in conformity with the ASTM standard method for evaluating painted specimens.¹⁵ Each specimen was rinsed with a gentle stream of tap water at a temperature of $38 \pm 5^\circ\text{C}$. Each wet specimen was scraped vigorously with a dull knife (scraper) to remove loose paint and corrosion products. The scraper was held with its face perpendicular to the surface of the specimen and parallel to the score mark and moved back and forth across the score mark.

The failure distances from the scribe line on each specimen were measured using a ⅛-in., quadrille ruled, transparent plastic grid. The failure distance is the perpendicular distance from the scribe line to the adherent paint. Therefore, the failure distance is a measure of the paint coating detached during the test. The average value of the failure distances was calculated from 34 measurements made at ⅛-in. intervals along the 2-in.-long scribe line.

Stressed C-ring Test

The SCC tests utilized C-ring type specimens. A C-ring SCC test specimen is shown in Figure 1. As described previously, the C-rings were machined from 1-in.-wide rings with 6-in.-outside diameters and ¼-in.-wall thicknesses. Each C-ring was stressed by means of a ¼-in.-diameter stainless steel bolt through two diametrically opposed ⅜-in.-diameter holes. Nylon bushings were used as shown in Figure 1 to prevent electrical contact between the stainless steel bolt and the specimen.

The C-rings were stressed by tightening the nuts on each end of the bolts. In this type of specimen, the maximum applied tensile stress, σ , is on the convex surface of the

Figure 1. The C-ring SCC Specimen.

C-ring, midway between the bolt holes. The maximum applied stress is calculated from the expression:¹⁶

$$\sigma = \frac{4EtZ\Delta}{\pi D^2}$$

where: σ = maximum applied tensile stress (psi)
 E = Young's modulus (psi)
 t = wall thickness (inches)
 Z = a correction factor (0.975)¹³
 Δ = $D_{\text{initial}} - D_{\text{final}}$ (the deflection of the outside diameter along the stressing bolt in inches)
 D = the initial, unstressed outside diameter (inches)

The five C-ring specimens used for this investigation were stressed to a maximum applied tensile stress of 100,000 psi (which was calculated using 18×10^6 psi for the modulus). The specimen stressing parameters are summarized in Table 2.

Table 2. C-ring Specimen Stressing Parameters. (100,000 psi).

Specimen Number	Outside Diameter (in.)	
	Initial	Stressed
1	6.058	5.607
2	6.039	5.588
3	6.023	5.572
4	6.068	5.617
5	6.029	5.576

Three C-rings (numbers 1, 2, and 3) were spray painted and the other two C-rings (numbers 4 and 5) were tested with as-machined surfaces.

The stressed C-rings were immersed in oxygen-saturated water containing 50 ± 1 -ppm chloride ions at $26 \pm 2^\circ\text{C}$. Oxygen saturation was achieved by continuously bubbling oxygen through the water in the environmental chamber. The 50-ppm chloride ion concentration was achieved by adding NaCl to distilled water. The chloride ion concentrations were determined with a chloride specific ion electrode.

The stressed C-rings were inspected daily and the time-to-failure (TTF) of each specimen was recorded. Since these were smooth specimens, this TTF is the sum of the time to nucleate a stress-corrosion crack and the time to propagate the crack through the specimen.

The painted C-rings which had not failed after more than one year (384 days) were removed from the test solution, scribed, and re-immersed in the same test solution. The C-rings were scribed by using a scribing tool to scratch a $1/16$ -in.-wide line through the paint and the underlying oxide to expose fresh metal. The scribed line was across the 1-in. width of the specimens, midway between the two bolt holes and extended across the $1/4$ -in. edge of the specimens. The purpose of scribing the C-rings was to show how effectively the paint coating would protect the substrate metal at flaws or scratches in the paint coating.

Fractured C-rings were examined metallographically to determine the microstructure and the fracture modes.

RESULTS AND DISCUSSION

The results of the laboratory analyses on two U-4.2 wt% Nb samples that were cut from two different C-ring specimens are shown in Table 3.

Table 3. The Results of the Laboratory Analyses on Two U-4.2 wt% Nb Samples (ppm).^{a,b}

Sample	C	O	Fe	Si	wt% Nb	Al	Be	Cu	Mn	Ni
1	80	530	50	40	4.33-4.31	20	10	10	5	20
2	110	420	60	50	4.72-4.73	30	5	10	5	10

^a C and O by a Leico total combustion analyzer. Si and Fe by atomic absorption. Nb by gravimetric analyses. Remainder by emission spectrographic analysis.

^b Emission spectrographic analyses also showed both C-rings contained:

< 1 ppm of B, Co, Li, Mg, Pb, Sb, and Sn.

<10 ppm of Ba, Bi, Ca, Cd, Cr, K, Mo, Na, Ti, and V.

<25 ppm of Zn.

The laboratory analyses showed that the primer component A, Chem-Glaze 9922-A, is an epoxy based on bisphenol-A and epichlorohydrin in a solvent system of methyl isobutyl ketone with a mixture of *ortho*-, *meta*-, and *para*-xylenes. The primer component B, Chem Glaze 9922-B, is a polyamide (from Di- or trimerized fatty acids and di- or polyamines). This curing agent is in a solvent system of isopropyl alcohol with a mixture of *ortho*-, *meta*-, and *para*-xylenes.

Emission spectrographic analysis indicated several cations were present in Chem Glaze 9922-A primer as shown in Table 4.

Table 4. Results of Emission Spectrographic Analysis of Chem Glaze 9922-A Epoxy Primer.

Cation	Amount ^a
Al	Minor
Ca	Minor
Cr	Major
Fe	Minor
K	Minor
Mg	Minor
Na	Minor
Si	Minor
Ti	Major
Zn	Major

^a Minor designates 0.1 to 1% by weight, and major designates greater than 1% by weight.

The laboratory analyses also showed that the cover coat, Urethane Z051, is a polyurethane resin based on a polyether and an isocyanate (polyoxypropylene and toluene diisocyanate). This polyurethane resin is in a solvent system of toluene, methyl isobutyl ketone, and *ortho*-, *meta*-, and *para*-xylenes.

Emission spectrographic analysis indicated that two cations were present in Urethane Z051. The two cations were potassium and sodium at levels of 35 and 40 ppm, respectively.

The six salt spray (fog) test specimens are shown in Figure 2 after being rinsed with tap water at the end of the 90-day exposure to the salt spray environment. This photograph shows that minor corrosion occurred on specimens 1, 2, and 3, but no attack is visible on specimens 4, 5, and 6.

Figure 3 shows the same six specimens after the loose paint and corrosion products have been scraped away. The average failure distances from the score marks are listed in Table 5.

Legend

1. Stainless steel wire hanger
2. Silicone rubber insulating gasket
3. Corrosion attack
4. Score mark
5. Photographic light reflection
6. Ink mark

Figure 2. Painted U 4.2 wt% Nb Specimens After 90-Day Test.

Table 5. The Results of the Salt Spray (Fog) Tests.

Sample No.	Average Failure Distance ^a (in.)
1	1/16
2	1/16
3	1/16
4	0
5	0
6	0

^a Perpendicular distance from the scribe line to the adherent paint.

Figure 3. Painted U-4.2 wt% Nb Specimens After Removal of Corrosion Products.

The three specimens which exhibited visible corrosion had an average failure distance of $1/16$ inch. The other three samples exhibited no corrosion.

The salt spray (fog) test can only determine the effective corrosion protection afforded by a coating in the salt spray cabinet atmosphere. The salt spray test cannot reproduce the natural marine atmosphere nor can it be used to predict accurate behavior of coatings in any other atmosphere.¹⁷

The results of the SCC tests on the stressed C-rings are summarized in Table 6.

Table 6 shows that the two uncoated C-rings failed after 2 to 16 hours (overnight) in the test solution while two painted C-rings had not failed after more than 9,000 hours in the test solution. A third painted C ring failed after 1008 hours, but the stress-corrosion crack on this C-ring nucleated where the substrate metal was exposed at a flaw in the paint coating. The flaw was a $1/16$ -square-inch area along the edge of the specimen where the paint had been chipped off.

Table 6. Results of the C-ring SCC Tests.^{a,b}

Coating	Time-to-Failure (number/hours)	Test Time with No Failure (number/hours)
Uncoated	2/<16 ^c	None
Paint ^d	1/1008 ^e	2/>9000
Scribed ^f	1/312, 1/480	None

^a The C-ring specimens were stressed to a maximum applied tensile stress of 100,000 psi.

^b The environment was oxygen-saturated water containing 50 ppm chloride ions at $26 \pm 2^\circ\text{C}$.

^c The time-to-failure of both specimens was between 2 and 16 hours (overnight).

^d The paint system is Chem Glaze® Epoxy Primer 9922 and Chem Glaze® Urethane Clear Gloss Z051 cover coat.

^e The painted C-ring fractured where the paint was chipped away to expose about $1/16$ square inch of metal.

^f The scribed C-rings were obtained by scribing the painted specimens after over 9,000 hours of testing as described in the text.

Both of the C-rings that were scribed after 9,000 hours in the test environment failed in less than 500 hours.

A scribed C-ring that failed after 312 hours of testing is shown in Figure 4. This specimen cracked along the scribe mark. The other scribed specimen, which failed after 480 hours, cracked parallel to, but $1/8$ in. away from, the scribe mark.

The photomicrographs in Figures 5 through 7 show a cross-section along the 1-in. width of the fracture surface of an uncoated C-ring that failed after less than 16 hours in the test environment. The intergranular SCC fracture edge is

Figure 4. A Painted and Scribed C-ring Specimen that Failed After 312 Hours.

Figure 5. Photomicrograph Showing Intergranular SCC Fracture Mode. 400X.

Figure 6. Photomicrograph Showing Intergranular SCC Fracture Mode and Secondary Transgranular SCC Cracks. 400X.

Figure 7. Photomicrograph Showing Transgranular Mechanical Fracture Mode. 400X.

shown in Figures 5 and 6. Figure 6 also shows some secondary intergranular SCC cracks. The transgranular mechanical fracture edge is shown in Figure 7.

These results show that the paint system will protect the aged U-4.2 wt% Nb substrate metal from SCC in an aqueous chloride environment only if the paint coating contains no flaws. If a flawless paint coating is scratched or otherwise damaged to expose substrate metal, SCC will occur providing that the tensile stress and environmental conditions are favorable. Accordingly, a painted U-4.2 wt% Nb alloy part that is subject to surface tensile stresses and is exposed to moisture, oxygen, and chloride ions will probably fail by SCC at flaws or scratches in the coating. Therefore, the paint system does not provide effective protection from SCC because it does not protect the substrate metal at flaws in the coating. Other paint systems might provide SCC protection at flaws in the paint coating.

CONCLUSIONS

The aged U-4.2 wt% Nb alloy can be protected from corrosion in a marine atmosphere by coating with the epoxy primer-polyurethane cover coat paint system described in this report.

An aged U-4.2 wt% Nb alloy component that is subjected to the appropriate surface tensile stresses will fail by SCC in aqueous chloride environments. If the component is coated with the paint system described in this report, it will fail by SCC at flaws or scratches in the paint coating.

Therefore, the paint system does not effectively protect the substrate metal from SCC in aqueous chloride environments because it does not protect the substrate metal at flaws and scratches in the coating.

REFERENCES

1. R. J. Jackson and J. F. Boland, "Mechanical Properties of Uranium-Base Niobium Alloys," USAEC RFP-1703, Rocky Flats Division, Dow Chemical U.S.A., June 17, 1971.
2. R. J. Jackson and J. F. Boland, "Physical, Chemical, and Technical Properties of the Uranium-4 wt% Niobium Alloy," USAEC RFP-1681, Rocky Flats Division, Dow Chemical U.S.A.
3. N. J. Magnani, "Stress Corrosion Cracking of Mulberry," *Corrosion*, 26, 406 (1970).
4. G. A. Witlow, "Stress Corrosion of Uranium Alloys," AWRE-O-49/66, July 1966.
5. C. A. W. Peterson and W. J. Steele, "Delayed Cracking Study in U-7.5 wt% Nb-2.5% Zr," UCID-15256, December 1967.
6. C. A. W. Peterson and R. R. Vandervoort, "Stress Cracking in the U-10% Molybdenum Alloy," UCRL-7767, March 1964.
7. B. D. McLaughlin, L. L. Stephenson, and C. J. Miglionico, "Influence of Aging Time and Temperature on the Susceptibility of γ -Quenched U-5 wt% Nb Alloy to SCC," *Corrosion*, 28, 35 (1972).
8. N. J. Magnani and H. Romero, "A Study of the Stress-Corrosion Cracking Behavior of Mulberry (U-7.5 wt% Nb-2.5 wt% Zr)," SC-RR-70-371, May 1970.
9. L. L. Stephenson, "A Survey of Factors Which Influence Stress Corrosion Crack Initiation in Several Uranium Base Alloys," SC-DR-70-718, October 1970.
10. N. J. Magnani and H. Romero, "The Effect of Chloride Ions on the Susceptibility to Stress Corrosion Cracking of U-7½ wt% Nb-2½ wt% Zr and U-4½ wt% Nb Alloys," SC-RR-70-860, December 1970.
11. J. M. Macki and R. L. Kochen, "The Stress-Corrosion Cracking Behavior of the U-4.2 wt% Nb Alloy Aged 80 Hours at 260°C," USAEC RFP-1824, Rocky Flats Division, Dow Chemical U.S.A., to be published.
12. Standard Method of Salt Spray (Fog) Testing (ASTM Designation B117-64), Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia (1971).
13. Standard Method of Acetic Acid-Salt Spray (Fog) Testing [ASTM Designation B287-62 (1968)], 1971 Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia (1971).
14. Standard Method of Test for Copper-Accelerated Acetic Acid-Salt Spray (Fog) Testing (Cass Test) (ASTM Designation B368-68), 1971 Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia (1971).
15. Standard Method of Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments [ASTM Designation D1654-61 (1968)], 1971 Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia (1971).
16. Stress-Corrosion Testing, ASTM Special Publication Number 425, The American Society for Testing and Materials, Philadelphia (1967).
17. K. G. Compton, "Atmospheric Corrosion," NACE Basic Corrosion Course, Chapter 4, National Association of Corrosion Engineers, Houston (1970).