

171448

171448

4

AGARD-AR-25-70

AGARD-AR-25-70

# AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

7 RUE ANCELLE 92 NEUILLY-SUR-SEINE FRANCE

ADVISORY REPORT No. 25

on

## Standardization of Test Methods for Stress-Corrosion Cracking

by

D. E. Piper

NORTH ATLANTIC TREATY ORGANIZATION



DISTRIBUTION AND AVAILABILITY  
ON BACK COVER



NORTH ATLANTIC TREATY ORGANIZATION  
ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT  
(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

**STANDARDIZATION OF TEST METHODS  
FOR STRESS-CORROSION CRACKING**

Working Group on Stress Corrosion of  
Structures and Materials Panel of AGARD

D. E. Piper

The Boeing Company  
Commercial Airplane Group  
Seattle, Washington 98124  
U.S.A.

The material in this publication has been reproduced  
directly from copy supplied by AGARD.

Published December 1970

620.194.2



*Printed by Technical Editing and Reproduction Ltd  
Harford House, 7-9 Charlotte St. London. W1P 1HD*

## FOREWORD

Following a preliminary review of the existing state of knowledge on the standardization of test methods for stress corrosion cracking, Dr D.E.Piper was appointed as coordinator for the Working Group on Stress Corrosion of the Structures and Materials Panel of AGARD.

In this capacity he made a survey of the techniques employed in a number of NATO nations. This report is a synopsis of the survey which was carried out in Norway, The Netherlands, Belgium, France, Italy, Germany, the UK and North America. The survey revealed that several organizations in Europe and North America were either examining the feasibility of standardizing test techniques or actually conducting comparative testing programs at different laboratories.

It was generally agreed by the sources visited that a standardization of test methods for stress corrosion cracking would be extremely useful provided that the standardized methods yielded data that are reproduceable, discriminative and interpretable from an engineering and scientific viewpoint. In view of this feeling and the great interest shown in the member countries of NATO in techniques for stress corrosion cracking testing, and after detailed discussion by the Working Group and the Panel, the Panel is planning a Workshop Conference in 1971 with special emphasis on: (1) a programme to enable a comparison of the work towards standardization of test techniques in the U.S.A. and Europe is recommended and (2) efforts should be made to produce a standard system for testing which will enable comparisons to be made directly between results obtained in different laboratories.



## STANDARDIZATION OF TEST METHODS FOR STRESS-CORROSION CRACKING

D. E. Piper

### Introduction

As Coordinator to the Working Group on Stress Corrosion of Structures and Materials Panel of AGARD, it was my task to survey the laboratories in Europe and North America and to report on the test methods used to measure susceptibility to stress-corrosion cracking (SCC) with special reference to the possible standardization of techniques.

The European survey was conducted between May 30 and July 4, 1969, when 29 laboratories were visited. Of this number, nine may be classified as research institutes: six as aircraft manufacturers, users, or laboratories; four as universities; two as corrosion centers; and eight as metal producers. The research project at National Aerospace Laboratory, Amsterdam, was reported to me by Mr H.P. Van Leeuwen at the 28th Panel meeting in Dayton. A synopsis of the European survey is included in this report. The North American survey was accomplished in my capacity as project director of the Boeing component of the ARPA Coupling Program on Stress-Corrosion Cracking and as chairman of ASTM's committee G01.06.04 on Standardization of Pre-cracked Specimens for SCC. The summary conclusions of this North American survey are included in the final section of this report: "Discussion and Recommendations".

The European centers visited were recommended by the offices of the national coordinators of Norway, the Netherlands, Belgium, France, Italy, Germany, and the United Kingdom. The techniques used by this broad classification of laboratories demonstrated that the choice of test methods is often determined by the reason for conducting the stress-corrosion test. Most stress-corrosion tests were conducted either to evaluate a material for a specific service application or to compare the relative behavior of individual alloys or various heat treatments of one alloy in a specific environment. Scientists conducting mechanism studies at the universities and research institutes also recognized the requirement for an unambiguous SCC test to demonstrate different theories of cracking.

### Synopsis of European Survey

Central Institute for Industrial Research, Oslo, Norway

Research was proceeding on the physical metallurgy and stress-corrosion cracking of aluminum-zinc-magnesium alloys with special reference to the influence of alloying additions and heat-treatment condition. Weldable aluminum-zinc-magnesium alloys were also receiving attention with the objective of increasing strength without detracting from weldability and resistance to SCC. Bent-beam, tension, and tuning-fork specimens were stressed under constant-load conditions. Bent-beam specimens of welds were loaded in four-point bending by a lever system, tension specimens were stressed by a calibrated coil spring, and tuning-fork specimens were also loaded by a lever system. Specimens were prepared in a standard manner and constantly immersed in 3% NaCl plus 0.1% H<sub>2</sub>O<sub>2</sub> solution. The temperature of the room was controlled, and precautions were taken to avoid galvanic effects.

Materials Command of the Royal Norwegian Air Force, Oslo, Norway

Toured the maintenance hanger and inspected fighter aircraft purchased from other countries by the Norwegian Air Force. It was remarked that control of cracking, whether due to fatigue or SCC, was costly. The staff would prefer construction materials free from SCC. Failing this, they would appreciate information about the growth characteristics of existing cracks.

Royal Netherlands Aircraft Factory, Fokker, Schiphol-Oost, Netherlands

Visited the Materials and Process Division of Fokker. The charter for this division included manufacturing research and product development, with special emphasis on adhesive bonding and reinforced plastics. Stress-corrosion testing involved only a quality-control evaluation of incoming material. They use a tension specimen stressed under constant load to 75% of 0.2% proof stress in a sodium chloride plus sodium chromate bath. Fokker laboratories operate several salt-spray cabinets to American military or ASTM specifications to evaluate coatings (adhesives), exfoliation corrosion, and anodic-layer and oxide-layer properties.

It was indicated that although the salt-spray tests might be useful for quality control, they were generally not suitable for conducting a discriminating evaluation of the above-mentioned properties because (1) the data had too wide a spread, (2) examination of the specimens was tedious, (3) the tests were of long duration, and (4) the data did not correlate with service experience. Fokker cited examples to substantiate these observations.

Fokker believes it should invent its own technique before commencing SCC testing purely for alloy evaluation. It was suggested that a nondestructive test (such as by solution potential, internal friction, or maybe resistivity) would be ideal if correlation with previous data could be achieved. Fokker would like to know how dangerous existing cracks are in materials or components, since cracks might be present but unnoticed in moderately susceptible alloys. Fokker is now using precracked specimens in SCC experiments.

National Aerospace Laboratory NLR, Amsterdam, Netherlands

This laboratory has a research contract to evaluate forgings of 7079 and DTD 5024 in different heat-treatment conditions. A stress-corrosion cracking evaluation was included in this study.

Special forgings were designed to allow stress-corrosion specimens to be taken that could be stressed across the short-transverse grain direction. The specimens were similar to the tuning-fork type, but were U-shaped rather than square. The specimens were prepared in a standard fashion and attached to a ferris-wheel arrangement as highly stressed, constant-deflection specimens. The ferris wheel rotated once per hour to provide 10 min of immersion in 3% NaCl solution followed by 50 min of drying. Specimens were removed from the wheel at the first sign of a crack. Constant-load tests were also being conducted on tension specimens with circular cross sections.

Other studies at this laboratory included an evaluation of the SCC characteristics of 7075 and 7079 aluminum alloys in the short-transverse grain direction. Techniques involved tension specimens stressed in constant deflection by means of a frame and pre-cracked, single-edge-cracked plate specimens under constant load.

Metal Research Institute TNO, Delft, Netherlands

Preliminary discussions concerned high-strength and stainless steels and the phenomenon of hydrogen embrittlement. The researchers were interested in developing and evaluating steels used in building construction. Bent-beam specimens were three-point loaded by a lever system and totally immersed in 34% MgCl<sub>2</sub> at 106° C. The effect of surface condition had been evaluated and specimen preparation had been standardized. Saturated MgCl<sub>2</sub> at 150° C was considered too severe an environment. During one study, steel wires of 3 to 4 mm<sup>2</sup> cross-sectional area were stressed under a constant deadweight load of 150 kg/mm<sup>2</sup> in 1% NaCl and in H<sub>2</sub>S.

I next visited the Applied Physical Chemistry Group at TNO. Research was being conducted on the metallographic aspects of stress corrosion in austenitic stainless steels. The alloy 18/8 CrNi steel (AISI 304) was being tested both as electropolished plate material and as thin foils. The bent-beam specimens of plate material were exposed under static three-point bending while electrically isolated from the holder. The successive stages of the crack were investigated by means of plastic replica techniques with optical microscope, electron microscope, and microprobe analyzer. The study of the fracture surface was performed with the scanning electron microscope and by electron microscope extraction replicas.

Corrosion tests with thin foils were performed in a special Teflon specimen holder. Bending stresses were generated by clamping the thin foil in a 90° wedge. A bore in the specimen holder permitted contact with the environment of MgCl<sub>2</sub> (at a boiling point of 154° C).

The metallurgists at TNO considered accelerated tests most desirable, provided they did not modify the mechanism of SCC.

Laboratorium voor Metallurgie der Non-Ferrometalen en Electro-Metallurgie, University of Gent, Gent, Belgium

The primary objective of this university department was teaching. Fundamental and applied research were also being conducted, some being sponsored by industrial contracts. During discussions, it was agreed that a test technique involving specimens that were attractive both to fundamentalists and to engineers would be most welcome in the field of SCC. The laboratory operated a salt-spray cabinet to several ASTM specifications.

Centre National de Recherches Metallurgiques (CNRM), Liege, Belgium

CNRM has a close association with the University of Liege and the Cobalt Information Center. The center caters mainly to the steel industry but does conduct some research on titanium alloys and copper-base alloys. Stress-corrosion tests were underway in the steel and titanium alloy systems. Pre-cracked, single-edge-cracked plate specimens were employed in cantilever bending. It was the experience of the staff at CNRM that the aircraft industry was very demanding with regard to specifications, procedures, and materials properties. They felt that if the aircraft industry would provide the impetus in the SCC area, other industries would follow.

CEBELCOR, Brussels, Belgium

Professor Pourbaix described the scope of the working group on fundamental methods of testing and control in corrosion of the European Federation of Corrosion. It was desired that action be undertaken to codify fundamental methods of testing and control relating to corrosion. The methods should lead to results that are reproducible, selective, and interpretable from scientific and technical points of view. They should be achieved under conditions allowing an interpretation of the results of (1) accelerated technological tests, (2) nonaccelerated technological tests, and (3) conditions leading to good or poor behavior in service.

The program can be best summarized in the form of a matrix that describes the commitments of individuals from over 50 organizations from 18 countries. In the first category are the test methods proposed: fundamental electrochemical (potentiostatic and potentiokinetic) and nonelectrochemical techniques, accelerated and nonaccelerated technological tests, and SCC techniques. The second category requires identification of the metal or alloy system. The third category indicates the areas of industrial use (e.g., aerospace, oceanspace, petroleum, etc.). The final category requests organizations to indicate whether they can supply certified specimens (with identification of chemical analysis, heat-treatment condition, surface treatment, etc.) for the program.

The program is large and diverse and deals mainly with fundamental test techniques. Success will depend upon the cooperation and good will of the many organizations participating. Special care will be taken to collaborate closely with ASTM. The program just got underway during my visit to CEBELCOR.

Laboratoire Central de Sud Aviation, Hauts-de-Seine, France

Typical of many aerospace laboratories, this laboratory employed a variety of testing methods to compare the stress-corrosion susceptibility of various alloys in certain environments and to evaluate a specific service requirement with regard to SCC. To ensure that components would be tested under the type of stress they might encounter in service, constant-deflection and constant-load stressing techniques were available.

Aluminum alloys were evaluated in the short-transverse grain direction using tension specimens stressed under constant deflection in aluminum frames and in proving rings. An extremely useful jig was available in which strip or rod specimens of aluminum, titanium, or steel could be stressed in bending by either deadweight-loading the arm of the jig (via a pulley system) or deflecting the specimen by securing the extension arms with a tie-bar device. Snap-in bent-beam specimens of aluminum welds (limited) and steels were also used, especially for programmed and industrial exposure. For research or exploratory studies, a self-contained stress-corrosion jig was available that employed a coil spring to load a tension specimen. Specimens were sometimes machine-notched rather than smooth, and the laboratory had just commenced to evaluate titanium alloys by subjecting pre-fatigue-cracked, single-edge-cracked plate specimens to cantilever bending.

The environment used by Sud Aviation was 3% NaCl solution applied by a constant or alternate (10 min of immersion followed by 50 min of drying) immersion method, the latter procedure being more popular. The duration for constant-immersion tests was three months; for alternate immersion, one month. Specimens were generally stressed initially at 80% of 0.2% offset tensile yield strength; if necessary, the stress level was subsequently lowered to establish a threshold stress. Care was always taken to control surface preparation.

CEFRACOR, Paris, France

CEFRACOR is the French Corrosion Center that monitors corrosion research in France and coordinates the research efforts of universities and industry. The center provides and stores information on corrosion studies. CEFRACOR is a member of the European Federation of Corrosion. The chief administrator, Mr. P. Orlowski, arranged for me to meet with several experts in stress corrosion to

discuss various aspects of my European survey. The relationship between CEFRACOR and the universities was explained, as was the extent and the location of the aerospace, steel, light-alloy, and special-alloy industries in France.

The experts present discussed their stress-corrosion studies, which were essentially of a fundamental nature and concerned high-purity and commercial steels. A program involving the establishment of testing procedures for 304-type stainless steel was described. Self-stressed beams in three- and four-point bending were tested in 44%  $MgCl_2$  (boiling point = 153°C) by six laboratories. The stress levels were kept constant, but three surface conditions—pickle, sand blast, and machined—were employed. The data from the laboratories collated extremely well. In the discussion it was mentioned that autoclave work required bent-beam specimens stressed by constant-deflection techniques.

The view was also expressed that the sensitivity of the magnesium chloride test for stainless steels is so influenced by impurities in the  $MgCl_2$  that the laboratory data are not always compatible with industrial service experience.

I also visited the laboratory of Professor Paul Lacombe at the Faculty of Science in Orsay, where investigations were underway concerning the SCC of high-strength carbon steels, maraging steels, and martensitic steels. The role of hydrogen was being studied using radioactive methods of tritium detection. Pre-fatigue-cracked, single-edge-cracked plate specimens were being considered along with conventional smooth specimens for the evaluation of SCC characteristics.

Pechiney, Centre de Recherches de Voreppe, Voreppe, France

Applied and fundamental research are conducted at Voreppe in support of the Pechiney group of companies. Experimental and commercial aluminum alloys are developed and evaluated for specific applications that include aerospace. The center has an excellent pilot facility for developing fabrication processes. Stress-corrosion tests are conducted to compare the susceptibility of different aluminum alloys or of one alloy in various heat treatments in standard environments.

A variety of test methods was available, the choice depending upon the specimen dimensions (indirectly, the load capability of the stressing facility). The load requirements varied on tension specimens that were loaded by a stiff tensile proving ring. A testing jig with a clothespin or scissors action could be spring-loaded to a maximum of 500 kg. Tuning-fork-type and U-bend specimens were also employed. The electrolyte was generally 3% NaCl solution buffered to a pH of 8 to 8.2 or 4 and alternately applied to the specimen (10 min of immersion followed by 50 min of drying). Test durations were of the order of one to two months.

The Pechiney laboratory is participating in a testing program initiated by the Panel on Stress Corrosion Testing Methods of the Committee International for the Development of Aluminum Alloys (CIDA). The total project involves participation by centers in Italy (ISML, Divisione Ricerche, Novara), Switzerland (Aluminum Suisse, Neuhausen a Rheinfalt), Germany (Leichtmetall Forschungsinstitut de VAW, Bonn), and England (British Aluminum Company Ltd., Gerrards Cross, Bucks., and Aluminum Labs Ltd., Banbury, Oxon.). Specimens approximately 9 in. in length are stressed to 75% of 0.2% offset tensile yield strength by a coil spring mounted above a rectangular frame that contains the tension specimen. The electrolyte of 3% NaCl solution, buffered to a pH of 5.0 to 5.4, is circulated around the specimen. The maximum load that can be applied by the spring is 1,200 kg.

Laboratorio Centrale, Fiat, Turin, Italy

At the central laboratory of Fiat, research and development are conducted on steels (about 80%, mainly in support of the auto industry), aluminum alloys (about 18%, in support of aircraft industry), and brasses (about 2%, for radiator fittings, etc.). Stress-corrosion testing of high-strength aluminum alloys employs a bent-beam specimen stressed in four-point bending under constant load in a sturdy testing frame that contains a built-in coil spring. A tension specimen stressed in a similar manner but containing a centrally machined hole was under investigation at Fiat. The environment generally used was 3.5% NaCl solution with pH adjusted to 4.2 by addition of acetic acid. Alternate-immersion procedures were 10 min of immersion followed by 50 min of drying and 15 min of immersion followed by 45 min of drying. Constant-immersion experiments were also conducted, the solutions being replaced when the pH changed significantly or the tanks became contaminated. Fiat has many special corrosion tests for specific applications; e.g., the CASS (copper acid salt spray) test for chromium-plated stainless steel. Fiat also operates a fog chamber to ASTM specifications.

The service experience with high-strength aluminum alloys was discussed with personnel at the aerospace division of Fiat. Stress-corrosion cracks had been discovered in a 7079-T6 component. The similar smooth-specimen thresholds for 7075 and 7079 in the standard sodium chloride alternate-immersion test did not accurately reflect the poor service experience with 7079. Fiat would like a stress-corrosion test that discriminates between alloys and alloy tempers and that also accurately predicts the behavior of the alloy in service. Preliminary data from precracked specimens, especially with respect to distinguishing between 7079 and 7075, indicate that a test using this type of specimen might satisfy Fiat's requirements. In light of this, Fiat is conducting tests on high-strength aluminum alloys such as 7075-T6 using single-edge-cracked plate specimens crackline-loaded by constant deflection.

ISML, Divisione Ricerche, Novara, Italy

The stress-corrosion laboratory at ISML is kept at a temperature of 20°C  $\pm$  0.5°C and at a relative humidity of 60%. Stress-corrosion specimens taken in the short-transverse grain direction were of the tension type (50 mm long, 2.9 mm in diameter) and the tuning-fork type (40 mm thick, 138 mm long). Tension specimens were spring-loaded, whereas tuning-fork specimens were subjected to a constant load by means of a lever system. Tension specimens 155 mm long were utilized in an anodic current test. C-ring specimens have also been used at ISML. Constant- and alternate-immersion tests are conducted in 5.3% NaCl solution. ISML is participating in the CIDA test program described in the Pechiney report.

ISML has been conducting extensive research in the field of high-strength aluminum-zinc-magnesium-copper alloys for forging and extrusion applications. Their experimental alloys contain additions of zirconium, zirconium plus manganese, and zirconium plus silver. Also being developed are new thermomechanical treatments for aluminum alloys. Because stress-corrosion resistance is a major consideration in this work, the metallurgists at ISML were very interested in the use of precracked specimens to characterize SCC in the short-transverse grain direction in high-strength aluminum alloys.

Instituto di Recerche Breda, Milan, Italy

Steel research was the main theme at Breda and constituted approximately 80% of all investigations. The remaining work was on copper and aluminum alloys. SCC work has commenced on AISI 4340 using pre-fatigue-cracked, single-edge-cracked plate specimens in cantilever bending, but need experience in this field. Therefore, Breda would be eager to participate in testing programs.

Max Planck Institut für Metallforschung, Stuttgart, Germany

Dr. L. Graf was my host at Max Planck, where I was introduced to several graduate students interested in the fundamental aspects of SCC. They wanted to learn about the new methods being developed to study stress-corrosion-crack growth rates and crack-arrest phenomena. I also talked extensively with the director of the institute, Professor Engell, about the testing techniques for SCC with special reference to those that might provide quantitative information about the stress-corrosion mechanism.

Metallgesellschaft, Frankfurt am Main, Germany

Metallurgists at the central laboratory in Frankfurt have conducted research into the physical metallurgy and SCC of titanium and titanium alloys. Specimens of Ti-6Al-4V were stressed at 50% and 75% of 0.2% offset tensile yield strength at temperatures of 300° C and 450° C and subjected to different relative humidities. Time to failure was plotted against relative humidity to express the material characteristics in this environment. Similar tests are to be conducted on Ti-6Al-4V specimens coated with artificial sea salt. The tension specimens were deadweight-loaded at temperature by a lever system.

Leichtmetall Forschungsinstitut der Vereinigte Aluminium Werke (VAW), Bonn, Germany

In this laboratory several stress-corrosion testing methods were employed. In the principal technique used, a tension specimen was stressed under constant load in a test jig while in a horizontal position. VAW is also participating in the CIDA test program (see the Pechiney summary). A simple and rapid test that can be used for the qualitative determination of sensitivity to SCC in the short-transverse grain direction was described. The procedure is called the cut-edge method. Test pieces of arbitrary dimension are cut or stamped out. The internal stresses produced in the test piece cause splitting or cracking of the edges when they are exposed to a corrosive medium.

DFVLR-Institut für Werkstoff Forschung, Porz-Wahn, Germany

The electrochemical aspects of the stress-corrosion cracking of titanium alloys were discussed. The staff was about to commence studies in this field and requested information about testing methods (fracture mechanics approach) and other investigations into the metallurgical and electrochemical aspects of SCC in titanium alloys.

Fried Krupp, GMBH, Essen, Germany

Limited experiments were being conducted on the hot-salt SCC characteristics of Ti-6Al-4V alloy. Tension specimens were deadweight-loaded to 75% of 0.2% offset tensile yield strength in pure dry HCl at 300° C.

Otto Fuchs, Meinherzhagen, Germany

Fuchs is mainly concerned with the production of die forgings of all sizes, and high-strength aluminum-alloy die forgings occupy a prominent position in the manufacturing program. Aircraft companies are major customers of Fuchs. We discussed the highly competitive nature of the deep-hardening, high-strength aluminum-alloy field, with special reference to the copper plus chromium plus silver additions favored by Fuchs. It was realized that a more discriminating test would be advantageous. Fuchs has been experimenting with different electrolytes and favors M/100 HCl + 0.2% Na<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> over M/100 HCl, 3.5% NaCl, and 3.5% NaCl + 0.2% Na<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>. The first solution is the most severe laboratory environment, whereas the last is the weakest. Fuchs uses tension specimens, tuning-fork-type specimens, and C-ring specimens; the tension specimens are spring-loaded, while the others are constant-deflection types. Material is always evaluated in the short-transverse grain direction.

High Duty Alloys Ltd., Slough, England

High Duty Alloys products are about 85% aluminum alloys, the remainder being titanium alloys and special orders. During stress-corrosion testing, tension test pieces were stressed in coil-spring jigs that incorporated levers with an 11:1 ratio. The round tension specimens were 3 in. long and 0.1 sq in. in cross-sectional area. The laboratory, which contained 70 of these jigs, was controlled at a temperature of 21° C and maintained at a relative humidity of 80%. The specimens were sprayed twice each working day with 3.5% NaCl solution (pH = 6.8). Similar coil-spring jigs without the lever system were located in the laboratory, the spring being placed beneath the specimen frame. Other stress-corrosion test techniques employed by HDA included (1) impressed anodic current tests and (2) C-ring specimens subjected to complete or alternate immersion in NaCl solution mainly to comply with customer requirements regarding acceptance of products.

Atmospheric stress-corrosion testing jigs were similar to those devised by Black. Rectangular-section test pieces were highly stressed in four-point bending over a channel. The extension arm attached to each end of the test piece contained weights. The jigs were covered while the specimens were exposed to an industrial atmosphere on the roof of the laboratory. There was also a special atmospheric exposure test for channel-section products, in which a load was applied to one side of the channel by a lever. During analysis of stress-corrosion data, HDA uses the median value for time to failure and always reports all data. HDA has recently reported the stress-corrosion properties of several forged aluminum alloys that were evaluated using single-edge-cracked plate specimens crackline-loaded by constant deflection.

HDA also conducts stress-corrosion tests on titanium alloys. Room-temperature sensitivity to 3.5% NaCl, distilled water, and several anticipated service environments was determined on pre-fatigue-cracked, single-edge-cracked specimens subjected to cantilever bending. Hot-salt stress-corrosion tests on IMI titanium alloys were conducted at 350° C and 520° C.

Newcastle University, Newcastle, England

Dr. Parkins of the Department of Metallurgy is chairman of a working party on stress-corrosion test methods within the European Corrosion Federation. This working party will attempt to rationalize the testing situation in Europe by preparing a critical review of SCC testing techniques and perhaps by conducting a cooperative testing program. The chairman will be assisted by a committee of specialists. During my visit with Dr. Parkins, a short course on stress-corrosion cracking was being presented at the metallurgy department. I toured the department and talked with several postgraduate students about their research programs. Pre-fatigue-cracked steel specimens were being employed to evaluate the stress-intensity threshold,  $K_{Isc}$ .

Dr. Parkins has since contacted Dr. Craig, chairman of Subcommittee VI on Stress-Corrosion Cracking and Corrosion Fatigue of ASTM, requesting information about the structure and scope of this subcommittee and suggesting possible interaction between Europe and the United States on the establishment of standards.

British Aircraft Corporation Ltd., Filton Division, Filton, England

Stress-corrosion testing techniques employed cylindrical tension specimens 4 mm in diameter and 30 mm long. These were taken parallel to the short-transverse grain direction and machined in such a manner that, on exposure, the maximum fiber stress could be arranged to occur across the end grain of the material. The surface of each specimen was prepared in a standard manner. The specimens were stressed by means of the arrangement used by Sud Aviation. At BAC, the specimen was secured by nylon screws and flexed as a beam between two long plexiglass arms located perpendicular to the specimen. Deadweight loads were transmitted to the opposite ends of the extension arms by a pulley system.

The corrosion environment used was intermittent immersion in solution A3 of French Specification AIRO754 (30 gm sodium chloride, 1.25 gm boric acid, and 0.19 gm di-sodium hydrogen phosphate per liter of distilled water with pH adjusted to 8 by the addition of saturated sodium carbonate solution). The continuous hourly cycle of 10 min of immersion and 50 min of air drying was achieved by evacuating a pair of bellows on each rig, which raised the platform on which the solution container rested. The solution was renewed at weekly intervals.

The stressing arrangement used on outdoor exposure rigs operated on the same principle as that for the accelerated indoor test, except that one extension arm was fixed to a rigid beam and a weight was attached to the other arm. The rigs were exposed at two separate sites: (1) on the roof of a shelter outside the laboratory at Filton and (2) on a site provided by Hawker Siddeley Aviation on the outskirts of Manchester. The rigs were sheltered from direct rainfall, and screens were also placed strategically to prevent excessive movement of the weights under windy conditions.

British Non-Ferrous Metals Research Association, London, England

BNFMRA was conducting a survey on stress-corrosion testing methods for the aluminum industry. This survey consisted of an extensive literature survey followed by a testing program. Specimen types being considered for this project included (1) C-ring, (2) bent beam (under constant load and constant deflection), (3) direct tension, and (4) precracked, single-edge-cracked plate stressed under constant load by crackline bending. I indicated that a longer version of the latter specimen was being used extensively in the United States along with self-stressing techniques involving constant deflection.

The stress-corrosion apparatus was located in the BNFMRA laboratories and on the roof of the building (atmospheric exposure tests). Tension-type specimens were stressed under constant load in spring-loaded self-contained frames that were housed in a laboratory maintained at 80° F and 85% relative humidity. Specimens were sprayed twice daily with 3% NaCl. Tension specimens stressed under constant load by steel coil springs via a lever were also employed.

Alcan Research and Development Ltd., Banbury, England

The Alcan Research Laboratory is participating in the CIDA test program (described in the Pechiney summary). This organization has employed conventional and electrochemical tests to characterize stress-corrosion cracking. Because they were primarily involved in the development of aluminum alloys that are resistant to SCC, Alcan had a great interest in test methods that were more discriminating than those currently available. To this end, pre-fatigue-cracked, single-edge-cracked plate (compact tension) specimens stressed under constant load by crackline bending were being employed. During my visit, I described the longer version of this specimen (double cantilever beam), which could be mechanically initiated and self-stressed. The staff intended to try this specimen in the near future.

Royal Aircraft Establishment, Farnborough, England

At RAE, Mr. Brooks had plans to conduct a test program on steels, based upon smooth bar specimens, in collaboration with other aircraft companies. RAE has experience with most of the conventional specimens and procedures for SCC testing, and the capability to perform fracture tests would definitely facilitate any future plans to conduct tests on precracked fracture specimens. Coil-spring and deadweight tension jigs were located in special rooms at controlled temperature and humidity.

BISRA, Sheffield, England

Dr. M. J. May and his staff at the metallurgy division of BISRA are very active in the field of fracture. We discussed the analysis of stress-corrosion cracking by fracture mechanics methods with special reference to the eventual standardization of test methods and the proper use of fracture mechanics terminology.

Brown-Firth Research Laboratories, Sheffield, England

The apparatus used for stress-corrosion testing was of the simple stress-rupture type using small tension-type test pieces loaded by a simple lever system by weights. The parallels of the specimens were 1 in. long; the diameter was sometimes varied to modify the stress. Liquid test environments were contained in small glass vessels that surrounded the specimens (constant immersion, usually in 3% NaCl). The machines used for tests in the heavily polluted industrial atmosphere were located on the roof of the laboratory.

Fracture mechanics (or precracked) specimens were being employed extensively by Brown-Firth during the evaluation of steels that had already been characterized by tests on conventional smooth specimens. Single-edge-precracked plate specimens were being stressed in cantilever bending in 3% NaCl solution. Data were expressed as initial stress intensity,  $K_{II}$ , versus time to failure, and the data were compared with conventional applied stress versus time-to-failure results.

### Discussion and Recommendations

The personnel at most of the laboratories visited during the survey agreed that a standardization of test methods for SCC would be extremely useful and emphasized that the recommended methods (or method) should yield data that are reproducible, discriminative, and interpretable from an engineering and scientific viewpoint. Further, it would be desirable if the particular standard written for stress-corrosion testing would simulate the service performance of the material or at least be representative of the most severe conditions to which the material would be subjected in service.

Because of the broad classification of laboratories visited during the survey and the small number of these that operated a permanent SCC test facility, it is difficult to express all comments in the correct perspective. In the case of the evaluation of high-strength and moderately resistant aluminum alloys, it was the lack of standard metallographic methods for recognizing and positively identifying the first appearance of a stress-corrosion crack (as distinct from a linear pit or an intercrystalline corrosion crack) on

constant-deflection-type specimens that hampered the reproducibility of time-to-first crack data. To avoid this, some laboratories relied on a constant-load-type test that yielded a time-to-failure parameter. The criticism of the use of this parameter to characterize the susceptibility of high-strength alloys has been well documented by those employing precracked-specimen techniques.

The major aluminum and steel companies in the United States employ precracked-specimen data to complement conventional smooth-specimen data. With the exception of studies of hot-salt environments, precracked specimens are used exclusively to determine the SCC properties of titanium and its alloys. The single-edge-cracked plate, stressed either in remote tension or remote three-point, four-point, or cantilever bending, is the most popular specimen type. Prior to my survey, precracked specimens were seldom employed in European laboratories, but since June 1969 several laboratories have reported test techniques that use precracked-specimen configurations. There were many discussions about the engineering significance of the test results generated by smooth- and precracked-specimen geometries. With regard to test techniques, it must be recognized that the amount of testing with precracked specimens is small compared with the vast quantity of smooth-specimen data generated on steels and aluminum alloys.

The environment also enters into the choice of test method. Most laboratories have adopted an alternate-immersion technique in 3.5% aqueous sodium chloride solution that was accomplished by any of several methods: (1) the solution was moved by air pressure or by a polyethylene pump from a tank to cover specimens that were stationary in a tray; (2) specimens were fixed to a corrosion-resistant rack that was lowered at intervals into a stationary tank containing the solution; or (3) specimens were fastened to a ferris-wheel arrangement by which they passed through a stationary tank or solution. The immersion cycle varied slightly at each laboratory, but the specimens were usually covered by salt solution for 10 min of each hour and uncovered for 50 min.

The standard test methods that deal with the alternate-immersion environment place stringent controls on the chemistry of the solution and the temperature and relative humidity of the laboratory or test chamber. Not all laboratories adhered strictly to the recommended practice; some preferred to totally immerse the specimen, thus avoiding the need for temperature and humidity control. However, data taken during total-immersion testing are influenced by the properties of the solution (e.g., aeration, temperature, etc.).

During alternate immersion, a stress level (e.g., 75% of 0.2% proof stress) and test duration are selected and the test run continuously for the time chosen or until failure has occurred, with interruptions only for changing the solution or examining specimens. For the case of high-strength aluminum alloys, a period of 30 days without failure of specimens has generally resulted in satisfactory performance of the alloy in service environments. However, several points concerning this popular environment were often discussed during the survey:

- 1) Because of the increased number of moderately resistant, high-strength aluminum alloys, the environment can no longer be relied upon to unambiguously rate or distinguish between the new alloy compositions developed by competitive organizations. Failures seldom occur, and thus the degree of susceptibility must be estimated after extensive sectioning followed by careful examination under the optical microscope. Some laboratories have made the solution extremely aggressive to prove a superior product, but the resulting data may have little chance of correlating with the field tests of the alloy.
- 2) Constant-deflection test specimens of overaged, high-strength aluminum alloys become severely pitted during the laboratory alternate-immersion test, especially if the duration of the test is extended beyond 30 days. Estimating the time to first crack is, therefore, extremely difficult. The composition of the alloy may also determine the surface condition of the specimen after the test and thus influence the predictability of the test data toward service performance.
- 3) There was some comment about the test duration of 30 days being too short a period. Aluminum alloys that pass this test have been known to exhibit a low threshold stress after prolonged testing in the atmosphere. Nevertheless, service performance has been generally satisfactory if specimens of an alloy survive the alternate-immersion test. However, more information will be required to anticipate the behavior of materials that are expected to perform during long missions (e.g., space probes). In this instance, complementary data about stress-corrosion-crack growth rate taken from precracked specimens of aluminum alloys and steels will be extremely valuable in controlling structural integrity in aggressive environments.

In light of the current activities on standardization of test techniques by the American Society for Testing and Materials (ASTM), the National Association of Corrosion Engineers (NACE), and the European Federation of Corrosion, it is recommended that no comparative study of the different methods of stress-corrosion testing be undertaken at this time. ASTM Subcommittee G01.06 on Stress-Corrosion Cracking and Corrosion Fatigue are currently recommending practices for the use of a variety of smooth and precracked specimens during stress-corrosion testing and establishing procedures for the use of many common laboratory environments. The Working Party on Stress Corrosion Test Methods of the European Federation of Corrosion is attempting to conduct a cooperative testing program that involves subjecting five different materials to five different test procedures and specific environments. It is anticipated that the tests will be complete by the spring of 1971. Several other testing programs are progressing at different levels of enthusiasm throughout the European community.

The member countries of NATO are extremely interested in the subject of testing, especially with respect to the newer fracture mechanics type of specimen. There is also a desire to maintain timely communication between the different task groups that are documenting practices and procedures for stress-corrosion testing. It was recommended by the Working Group on Stress Corrosion at the 30th Structures and Materials Panel of AGARD (April 1970) that a program for a workshop conference be prepared with special emphasis on:

- The comparison of the results of the attempts of the United States and Europe to standardize test techniques
- Discussion of the engineering utility and significance of the test results
- Topics that produced the most discussion during the survey; e.g., the microscopic identification of SCC and the measurement of the stress-corrosion characteristics of weldments



It was generally agreed by the sources visited that a standardization of test methods for stress-corrosion cracking would be extremely useful provided that the standardized methods yielded data that are reproducible, discriminative and interpretable from an engineering and scientific viewpoint.

This Report is sponsored by the Structures and Materials Panel of AGARD.

It was generally agreed by the sources visited that a standardization of test methods for stress-corrosion cracking would be extremely useful provided that the standardized methods yielded data that are reproducible, discriminative and interpretable from an engineering and scientific viewpoint.

This Report is sponsored by the Structures and Materials Panel of AGARD.

It was generally agreed by the sources visited that a standardization of test methods for stress-corrosion cracking would be extremely useful provided that the standardized methods yielded data that are reproducible, discriminative and interpretable from an engineering and scientific viewpoint.

This Report is sponsored by the Structures and Materials Panel of AGARD.

It was generally agreed by the sources visited that a standardization of test methods for stress-corrosion cracking would be extremely useful provided that the standardized methods yielded data that are reproducible, discriminative and interpretable from an engineering and scientific viewpoint.

This Report is sponsored by the Structures and Materials Panel of AGARD.

<p>AGARD Advisory Report 25 North Atlantic Treaty Organization, Advisory Group for Aerospace Research and Development STANDARDIZATION OF TEST METHODS FOR STRESS-CORROSION CRACKING D.E.Piper Published December 1970 12 pages</p> <p>This report is a synopsis of the survey which was carried out in Norway, The Netherlands, Belgium, France, Italy, Germany, the UK and North America. The survey revealed that several organizations in Europe and North America were either examining the feasibility of standardizing test techniques or actually conducting comparative testing programs at different laboratories.</p> <p>P.T.O.</p>	<p>620.194.2</p>	<p>AGARD Advisory Report 25 North Atlantic Treaty Organization, Advisory Group for Aerospace Research and Development STANDARDIZATION OF TEST METHODS FOR STRESS-CORROSION CRACKING D.E.Piper Published December 1970 12 pages</p> <p>This report is a synopsis of the survey which was carried out in Norway, The Netherlands, Belgium, France, Italy, Germany, the UK and North America. The survey revealed that several organizations in Europe and North America were either examining the feasibility of standardizing test techniques or actually conducting comparative testing programs at different laboratories.</p> <p>P.T.O.</p>	<p>620.194.2</p>
<p>AGARD Advisory Report 25 North Atlantic Treaty Organization, Advisory Group for Aerospace Research and Development STANDARDIZATION OF TEST METHODS FOR STRESS-CORROSION CRACKING D.E.Piper Published December 1970 12 pages</p> <p>This report is a synopsis of the survey which was carried out in Norway, The Netherlands, Belgium, France, Italy, Germany, the UK and North America. The survey revealed that several organizations in Europe and North America were either examining the feasibility of standardizing test techniques or actually conducting comparative testing programs at different laboratories.</p> <p>P.T.O.</p>	<p>620.194.2</p>	<p>AGARD Advisory Report 25 North Atlantic Treaty Organization, Advisory Group for Aerospace Research and Development STANDARDIZATION OF TEST METHODS FOR STRESS-CORROSION CRACKING D.E.Piper Published December 1970 12 pages</p> <p>This report is a synopsis of the survey which was carried out in Norway, The Netherlands, Belgium, France, Italy, Germany, the UK and North America. The survey revealed that several organizations in Europe and North America were either examining the feasibility of standardizing test techniques or actually conducting comparative testing programs at different laboratories.</p> <p>P.T.O.</p>	<p>620.194.2</p>

It was generally agreed by the sources visited that a standardization of test methods for stress-corrosion cracking would be extremely useful provided that the standardized methods yielded data that are reproducible, discriminative and interpretable from an engineering and scientific viewpoint.

This Report is sponsored by the Structures and Materials Panel of AGARD.

It was generally agreed by the sources visited that a standardization of test methods for stress-corrosion cracking would be extremely useful provided that the standardized methods yielded data that are reproducible, discriminative and interpretable from an engineering and scientific viewpoint.

This Report is sponsored by the Structures and Materials Panel of AGARD.

It was generally agreed by the sources visited that a standardization of test methods for stress-corrosion cracking would be extremely useful provided that the standardized methods yielded data that are reproducible, discriminative and interpretable from an engineering and scientific viewpoint.

This Report is sponsored by the Structures and Materials Panel of AGARD.

It was generally agreed by the sources visited that a standardization of test methods for stress-corrosion cracking would be extremely useful provided that the standardized methods yielded data that are reproducible, discriminative and interpretable from an engineering and scientific viewpoint.

This Report is sponsored by the Structures and Materials Panel of AGARD.

<p>AGARD Advisory Report 25 North Atlantic Treaty Organization, Advisory Group for Aerospace Research and Development STANDARDIZATION OF TEST METHODS FOR STRESS-CORROSION CRACKING D.E.Piper Published December 1970 12 pages</p> <p>This report is a synopsis of the survey which was carried out in Norway, The Netherlands, Belgium, France, Italy, Germany, the UK and North America. The survey revealed that several organizations in Europe and North America were either examining the feasibility of standardizing test techniques or actually conducting comparative testing programs at different laboratories.</p> <p>P.T.O.</p>	<p>620.194.2</p>	<p>AGARD Advisory Report 25 North Atlantic Treaty Organization, Advisory Group for Aerospace Research and Development STANDARDIZATION OF TEST METHODS FOR STRESS-CORROSION CRACKING D.E.Piper Published December 1970 12 pages</p> <p>This report is a synopsis of the survey which was carried out in Norway, The Netherlands, Belgium, France, Italy, Germany, the UK and North America. The survey revealed that several organizations in Europe and North America were either examining the feasibility of standardizing test techniques or actually conducting comparative testing programs at different laboratories.</p> <p>P.T.O.</p>	<p>620.194.2</p>
<p>AGARD Advisory Report 25 North Atlantic Treaty Organization, Advisory Group for Aerospace Research and Development STANDARDIZATION OF TEST METHODS FOR STRESS-CORROSION CRACKING D.E.Piper Published December 1970 12 pages</p> <p>This report is a synopsis of the survey which was carried out in Norway, The Netherlands, Belgium, France, Italy, Germany, the UK and North America. The survey revealed that several organizations in Europe and North America were either examining the feasibility of standardizing test techniques or actually conducting comparative testing programs at different laboratories.</p> <p>P.T.O.</p>	<p>620.194.2</p>	<p>AGARD Advisory Report 25 North Atlantic Treaty Organization, Advisory Group for Aerospace Research and Development STANDARDIZATION OF TEST METHODS FOR STRESS-CORROSION CRACKING D.E.Piper Published December 1970 12 pages</p> <p>This report is a synopsis of the survey which was carried out in Norway, The Netherlands, Belgium, France, Italy, Germany, the UK and North America. The survey revealed that several organizations in Europe and North America were either examining the feasibility of standardizing test techniques or actually conducting comparative testing programs at different laboratories.</p> <p>P.T.O.</p>	<p>620.194.2</p>



## NATIONAL DISTRIBUTION CENTRES FOR UNCLASSIFIED AGARD PUBLICATIONS

Unclassified AGARD publications are distributed to NATO Member Nations through the unclassified National Distribution Centres listed below

### BELGIUM

General J. DELHAYE  
Coordinateur AGARD - V.S.L.  
Etat Major Forces Aériennes  
Caserne Prince Baudouin  
Place Dailly, Bruxelles 3

### CANADA

Director of Scientific Information Services  
Defence Research Board  
Department of National Defence - 'A' Building  
Ottawa, Ontario

### DENMARK

Danish Defence Research Board  
Østerbrogades Kaserne  
Copenhagen Ø

### FRANCE

O.N.E.R.A. (Direction)  
29, Avenue de la Division Leclerc  
92, Châtillon-sous-Bagneux

### GERMANY

Zentralstelle für Luftfahrtokumentation  
und Information  
Maria-Theresia Str. 21  
8 München 27  
Attn: Dr Ing. H. J. RAUTENBERG

### GREECE

Hellenic Armed Forces Command  
D Branch, Athens

### ICELAND

Director of Aviation  
c/o Flugrad  
Reykjavik

### ITALY

Aeronautica Militare  
Ufficio del Delegato Nazionale all' AGARD  
3, Piazzale Adenauer  
Roma/EUR

### LUXEMBOURG

Obtainable through BELGIUM

### NETHERLANDS

Netherlands Delegation to AGARD  
National Aerospace Laboratory, NLR  
Attn: Mr A. H. GEUDEKER  
P.O. Box 126  
Delft

### NORWAY

Norwegian Defense Research Establishment  
Main Library, c/o Mr P. L. EKERN  
P.O. Box 25  
N-2007 Kjeller

### PORTUGAL

Direccao do Servico de Material  
da Forca Aerea  
Rua de Escola Politecnica 42  
Lisboa  
Attn: Brig. General Jose de Sousa OLIVEIRA

### TURKEY

Turkish General Staff (ARGE)  
Ankara

### UNITED KINGDOM

Ministry of Technology Reports Centre  
Station Square House  
St. Mary Cray  
Orpington, Kent BR5 3RE

### UNITED STATES

National Aeronautics and Space Administration (NASA)  
Langley Field, Virginia 23365  
Attn: Report Distribution and Storage Unit

\*\*\*

If copies of the original publication are not available at these centres, the following may be purchased from:

#### *Microfiche or Photocopy*

National Technical  
Information Service (NTIS)  
5285 Port Royal Road  
Springfield  
Virginia 22151, USA

#### *Microfiche*

ESRO/ELDO Space  
Documentation Service  
European Space  
Research Organization  
114, Avenue de Neuilly  
92, Neuilly-sur-Seine, France

#### *Microfiche*

Ministry of Technology  
Reports Centre  
Station Square House  
St. Mary Cray  
Orpington, Kent BR5 3RE  
England

The request for microfiche or photocopy of an AGARD document should include the AGARD serial number, title, author or editor, and publication date. Requests to CFSTI should include the NASA accession report number.

Full bibliographical references and abstracts of the newly issued AGARD publications are given in the following bi-monthly abstract journals with indexes:

Scientific and Technical Aerospace Reports (STAR)  
published by NASA,  
Scientific and Technical Information Facility,  
P.O. Box 33, College Park,  
Maryland 20740, USA

United States Government Research and Development  
Report Index (USGDRI), published by the Clearinghouse  
for Federal Scientific and Technical Information,  
Springfield, Virginia 22151, USA

