Application of ACCELERATED CORROSION TESTS *to* SERVICE LIFE PREDICTION *of* MATERIALS

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EDITORS

ASTM STP 1194

STP 1194

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ASTM Publication Code Number (PCN)
04-011940-27

ASTM
1916 Race Street
Philadelphia, PA 19103

Library of Congress Cataloging-in-Publication Data

Application of accelerated corrosion tests to service life prediction
of materials / Gustavo Cragnolino and Narasi Sridhar, editor.
(STP ; 1194)
"The ASTM Symposium on Application of Accelerated Corrosion Tests
to Service Life Prediction of Materials was held during 16-17 Nov.,
1992 in Miami, Fla. ... sponsored by ASTM Committee G-1 on Corrosion
of Metals"--Foreword
"ASTM publication code number (PCN) 04-011940-27
Includes bibliographical references and index.
ISBN 0-8031-1853-8
1. Corrosion and anti-corrosives--Testing--Congresses.
2. Accelerated life testing--Congresses. 3. Stress corrosion-
-Testing--Congresses. I. Cragnolino, Gustavo, 1940- .
II. Sridhar, Narasi, 1964- . III. ASTM Committee G-1 on Corrosion
of Metals. IV. ASTM Symposium on Application of Accelerated
Corrosion Tests to Service Life Prediction of Materials (1992 :
Miami, Fla.) V. Series: ASTM special technical publication ; 1194.
TA418.74.A67 1994
620.1'1223--dc20 93-47376
CIP

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Peer Review Policy

Each paper published in this volume was evaluated by three peer reviewers. The authors addressed all of the reviewers' comments to the satisfaction of both the technical editor(s) and the ASTM Committee on Publications.

To make technical information available as quickly as possible, the peer-reviewed papers in this publication were printed "camera-ready" as submitted by the authors.

The quality of the papers in this publication reflects not only the obvious efforts of the authors and the technical editor(s), but also the work of these peer reviewers. The ASTM Committee on Publications acknowledges with appreciation their dedication and contribution to time and effort on behalf of ASTM.

Printed in Ann Arbor, MI
February 1994

Foreword

The ASTM symposium on Application of Accelerated Corrosion Tests to Service Life Prediction of Materials was held during 16–17 Nov. 1992 in Miami, FL. It was sponsored by ASTM Committee G-1 on Corrosion of Metals. Gustavo Cragnolino and Narasi Sridhar, both of the Center for Nuclear Waste Regulatory Analyses in the Southwest Research Institute served as symposium cochairmen and editors of this publication.

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Overview

The initial impetus for this symposium was the long-term (hundreds to thousands of years) performance requirements in the disposal of high-level nuclear wastes that have driven the development of various life-prediction approaches for waste containers. Life prediction has also gained increasing importance in other applications due to aging facilities and infrastructure (for example, nuclear power plants, aircraft, concrete structures), heightened concerns regarding environmental impact (for example, hazardous waste disposal, oil and gas production, and transportation), and economic pressures that force systems to be used for extended periods of time without appropriate maintenance. Life prediction in the context of this publication pertains essentially to structures or systems that are undergoing corrosive processes. For systems subjected to purely mechanical failure processes such as fatigue and creep, life prediction techniques have advanced to a greater degree. Accelerated laboratory corrosion tests, which in the past have focused on screening tests for materials ranking and selection and quality control tests for materials certification, also have to be re-evaluated for their usefulness to life prediction. A major objective of this symposium was to provide a forum for discussing the approaches to life prediction used by various industries. A second objective, especially relevant to the mission of ASTM, was to discuss the appropriateness of various accelerated corrosion tests to life-prediction. The papers in this volume cover many industries, although some areas, such as nuclear waste disposal, are more heavily represented than others. However, the goal of being able to compare life prediction versus actual performance is yet to be achieved in many of the industries represented in this volume. The papers in this volume are classified into three sections: Laboratory and Field Analysis Techniques, Life Prediction Techniques in Various Applications, and Experimental Techniques.

Laboratory and Field Data Analysis Techniques

All the papers in this section describe various ways in which laboratory or field data can be extrapolated to predict service life. A systematic approach to design and life prediction, as described by Staehle, would entail a definition of environmental conditions, material conditions, and failure modes, all combined in a probabilistic framework. Several examples from the literature for the definition of failure modes are provided in this paper. One important aspect of this paper is the organization of experimental data in a potential-pH framework so that failure modes can be defined for a given material under a given set of environmental conditions. While the examples cited in this paper use the potential-pH diagrams as the basis for failure mode definition, other methods such as the definition of corrosion potential as a function of time can also be used to define failure modes. The latter approach is described in other papers in this volume (for example, Macdonald et al., Sridhar et al.). The use of Weibull statistics in defining the probability of failure by stress corrosion cracking is also illustrated by Staehle. Finally, the approach to predicting the overall probability of failure by a combination of failure modes, each with its own probability distribution is discussed. It must be noted that this approach can be combined with other methods of combining failure modes such as fault tree analysis. This method also differs from some of the other performance techniques that rely on developing an overall probability of failure through Monte-Carlo techniques whereby individual probabilities of various failure modes are not calculated separately. Nyborg and Lunde discuss an empirical crack-growth model along with a probabilistic assessment based on the uncertainties in the input parameters for the case of ammonia cracking of carbon steel storage tanks. While this model carries many uncertainties regarding the extrapolation of short-term crack-growth data to long-term prediction, the methodology illustrates the importance of early and periodic inspection in reducing failure probability. It also illustrates the sensitivity of failure probability to various material and design parameters, such that corrective actions can be pursued more effectively. The use of artificial neural network to synthesize both short-term laboratory data and longer-term field experience in similar environments to make expected service-life predictions in a rapid manner is discussed by Silverman. This technique is combined with an expert system to provide qualitative guidelines regarding the applicability of a specific material in a given environment for which only short-term data can be generated. McCuen and Albrecht discuss the use of various curve-fitting approaches in extrapolating atmospheric corrosion data collected for time periods ranging up to 23 years to predict end-of-service corrosion penetration at 75 years. They suggest that a composite model that combines a power-law behavior of corrosion penetration at short-times with a linear behavior at long-times is the most robust of the curve-fitting schemes. The uncertainties in predicted penetrations at 75 years due to the uncertainties in the assumed model are highlighted. Duncan et al. describe the use of empirically measured corrosion rates and Poisson distribution for failure to predict the cumulative probability of failure of transuranic waste drums stored at Hanford.

These papers also highlight the need for greater mechanistic (or deterministic as some prefer to call it) understanding of the various corrosion processes since extrapolations performed on the basis of parametric or statistical fitting of present data result in considerable variations in the predicted behavior, depending on the selection of the fitting method.

Life Prediction Techniques in Various Applications

The importance of an engineered barrier system in high-level nuclear waste disposal, as well as the interdependency of the engineering design and environmental conditions, is highlighted by Verink. The next six papers deal with various life-prediction techniques related to high-level waste disposal containers. The approach used by Ikeda et al. in predicting the performance of Ti containers involves the assumption that crevice corrosion initiation is inevitable under the Canadian vault conditions, but that propagation is limited by the availability of oxidants to the open surface. Hence, as time progresses, a deceleration of crevice corrosion propagation and eventual repassivation is predicted to occur. For the same repository and container design, Macdonald et al. use a variety of approaches to predict long-term performance. The mechanistic modeling of corrosion potential is of special importance because it can be used to determine the corrosion modes as a function of environmental factors. Macdonald et al. also calculate the upper bound in corrosion rate by assuming that rate of transport of oxygen or other radiolytic species determines the dissolution rate of Ti and show that the calculated corrosion rates are rather low. These models are further useful because they indicate the areas in which expenditures of experimental effort will be most fruitful. Beavers et al. also emphasize the need for mechanistic modeling and suggest that corrosion allowance materials whose corrosion rate can be well-defined coupled to a multibarrier system be given greater consideration for high-level nuclear waste packages in the U.S. program. Park et al. use fracture mechanics-based tests under a variety of loading conditions to measure stress corrosion crack growth rate of types 304L and 316L stainless steels and alloy 825 in repository groundwater environments concluding that no significant environmentally assisted crack growth was observed in these alloys. The limited environmental conditions examined makes it difficult to use this negative finding for long-term prediction. The approach suggested by Sridhar et al. is essentially similar to that of Ikeda et al., albeit for a different class of materials, namely Ni-based alloys and stainless steels. The long-term prediction is attempted by considering the evolution of corrosion potential and critical potentials (initiation and repassivation potentials) for localized corrosion. A crevice initiation model is presented and the use of repassivation potential as a bounding parameter for container performance assessment is examined. The need for detailed mechanistic justification of crevice repassivation potential and the shortcomings of the current models are pointed out. Sjöblom reviews a variety of scenarios to be considered for assessing the safety of copper containers in the Swedish high-level waste program.

The use and limitations of accelerated laboratory tests to predict service performance of nuclear reactor components are examined in the next two papers. Perkins and Shann show that a higher temperature laboratory test of various types of zircaloy fuel cladding can be used to distinguish the performance of these claddings in service. In contrast, Palumbo et al. warn that certain well-known accelerated laboratory tests may not be able to distinguish subtle variations in alloy 400 samples from two different lots that however, result in significant differences in service performance.

The last two papers in this section cover two widely different industries. The corrosion of oil and gas production components occurs under complex environmental and flow conditions. The paper by Kolts and Buck reviews various empirical correlations between corrosion or erosion rates and environmental and flow parameters. The corrosion and erosion of the infrastructure has become a topic of great concern both in the U.S. and elsewhere. Andrade and Alonso review the factors affecting the service performance of reinforced concrete structures, although the example they cite is mainly related to low-level radioactive waste vaults or bunkers. The importance of preventing or delaying the onset of active corrosion of steel is pointed out. It is also noted that unreinforced concrete structures have lasted for many centuries.

Experimental Techniques

A new index for crevice corrosion susceptibility, based on the concept of change from passive to active behavior due to IR potential drop is presented by Xu and Pickering. The advantage of this technique, in addition to being consistent with some of the observed crevice corrosion phenomena, is the ease with which it can be modeled on a mechanistic basis. A possible limitation may be its inapplicability to stainless steels and other highly passivating alloys. The use of graphite fiber wool as a crevice forming device to accelerate stress corrosion cracking of type 304 stainless steel and alloy 600 is examined by Akashi. The salient feature of this work is the use of exponential probability distribution in comparing the accelerated laboratory test to documented service life. Aaltonen et al. propose a multipotential test technique whereby a number of stress corrosion cracking specimens under a range of applied potentials can be exposed to a given environment simultaneously to determine critical potentials for stress corrosion cracking. The results of this type of test can be used to evaluate some of the proposed methodologies in papers on life prediction mentioned previously. Tsujikawa et al. examine the use of spot welded specimen, which simulates both the effects of crevices and residual stresses for predicting stress corrosion cracking. The important result from this paper is that the critical potential for stress corrosion cracking is the same as the repassivation potential for crevice corrosion. This simplifies the task of performance assessment considerably because one critical potential can be used to evaluate several failure modes. However, these results need further scrutiny. From the mechanical aspect, Louthan and Porr suggest that specimen geometry has a significant effect on stress corrosion cracking susceptibility as measured in slow strain rate tests. The use of electrochemical potentiokinetic reactivation (EPR) test method to characterize the extent of sensitization of some austenitic stainless steels has been relatively well-established. Some semi-empirical models exist that use the EPR values to predict the susceptibility to stress corrosion cracking of certain nuclear reactor components. The EPR technique is extended to the case of a duplex stainless steel by Verneau et al.

A novel method to evaluate atmospheric corrosion beneath a thin electrolyte layer under heat transfer conditions is presented by Muto et al. The interesting feature of this paper is the comparison of accelerated laboratory test results using a rating number derived from Weibull distribution parameters to rating number from field exposure tests. The applicability of this test technique to studying corrosion under repeated wet and dry cycles and to moist environments needs to be examined.

The need for long-term life prediction of components exposed to corrosive conditions necessitates a re-evaluation of many of the accelerated corrosion test methods that are being used at present. As many of the papers in this volume suggest, the comparison between accelerated laboratory tests and service life data must be made in a statistical framework. The evaluation of appropriate test methods will also be aided by the simultaneous development of predictive models. It is hoped that the papers contained in this volume will stimulate further examination of the present-day corrosion test methods, many of which are contained in ASTM standards. We wish to thank the authors for their efforts in the publication of this volume. We also wish to thank the reviewers for their assistance in improving the quality of this publication, the ASTM staff and Mr. Arturo Ramos for their timely assistance in organizing the symposium and assembling this publication. Finally, we wish to thank Dr. Michael Streicher and Mr. Jefferey Kearns who provided the initial encouragement in organizing this symposium.

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ISBN: 0-8031-1853-8