CORROSION TESTS AND STANDARDS

APPLICATION AND INTERPRETATION

2ND EDITION

ROBERT BABOIAN, EDITOR

ASTM INTERNATIONAL
Standards Worldwide

Corrosion Tests and Standards: Application and Interpretation—Second Edition

Robert Baboian, Editor

Section Editors

Robert Baboian
Sheldon W. Dean, Jr.
Harvey P. Hack
Edward L. Hibner
John R. Scully

ASTM Stock Number: MNL20—2nd

ASTM International
100 Barr Harbor Drive
PO Box C700
West Conshohocken, PA 19428-2959

Printed in the U.S.A

Library of Congress Cataloging-in-Publication Data

Corrosion tests and standards : application and interpretation / Robert Baboian, editor ; section editors, Robert Baboian ... [et al.].—2nd ed.
p. cm.—(ASTM manual series ; MNL 20)
ASTM Stock Number: MNL20—2nd
ISBN 0-8031-2098-2
1. Corrosion and anti-corrosives—Testing. I. Baboian, Robert. II. Series.

TA462.C666 2005
620.1'1223—dc22

2004025972

Printed in Baltimore, MD
January 2005

THE EDITORS

ROBERT BABOIAN,

Editor

Robert Baboian is a corrosion consultant with RB Corrosion Service. He received his B.S. degree in chemistry from Suffolk University in 1959 and his Ph.D. in physical chemistry from Renssalaer Polytechnic Institute in 1964. He did postdoctoral research at the University of Toronto in 1964 and subsequently received a faculty appointment to Senior Research Associate in 1965. He joined the Materials and Controls Group of Texas Instruments, Inc. in 1966, where he established the Electrochemical and Corrosion Laboratory. He retired from Texas Instruments in December 1996 as Principal Fellow and Head of the Electrochemical and Corrosion Laboratory. The Principal Fellow position at TI is the company's highest honor for scientific and technical achievement. He is an ASTM Honorary Member, a Fellow of ASTM, NACE, and SAE, and was a Ford Foundation Postdoctoral Fellow in 1964.

Dr. Baboian has been dedicated to the research and development of corrosion resistant materials and devices, environmental effects on materials, and the use of electrochemical techniques in corrosion testing for almost 40 years. He holds 15 U.S. patents, is the editor of 13 books, and has authored over 170 technical publications. He has served on a number of Government and Academic Committees and has lectured throughout the world, and his services were donated by TI to the National Park Service as a corrosion consultant on the Statue of Liberty restoration program. Recently, he has researched the sinking of the *Titanic* and has proposed theories on corrosion mechanisms causing the failure.

Recognized for his active involvement in the technical community, Dr. Baboian has received the Cavanaugh Award and the Award of Merit from ASTM, the ASTM Dudley Award for publications, the ASTM LaQue Award for outstanding contributions to corrosion testing and evaluation, the Speller Award for outstanding contributions in corrosion engineering, and the T. J. Hull Award for publications from NACE, the Science and Technology Award of the Suga Weathering Technology Foundation in Japan, the Vittorio de Nora Award from the Electrochemical Society, the Francis L. LaQue Award for contributions to marine corrosion and prevention from the LaQue Center Sea Horse Institute, and the National Materials Advancement Award from the Federation of Materials Societies. He has served on the Executive Committee and the Board of Directors of ASTM and NACE and was the Chairman of the ASTM Board of Directors in 1987. He also has chaired ASTM Committee G-1 on Corrosion of Metals, the SAE Automotive Corrosion and Protection Committee, and the NACE Research Committee.

SECTION EDITORS

SHELDON W. DEAN, JR. is currently the President of Dean Corrosion Technology, Inc., a consulting firm in Allentown, Pennsylvania that provides expert advice on matters involving corrosion of metals. He is also Editor in Chief of the *Journal of ASTM International*. He received his A.B. from Middlebury College and his B.S. and Sc.D. from the Massachusetts Institute of Technology. He has received the ASTM Award of Merit, the Charles B. Dudley Award, the Sam Tour Award, the Francis L. LaQue Memorial Award, the ASTM Committee on Publications Award for Excellence, the ASTM Committee G-1 Certificate of Appreciation, the NACE Frank Newman Speller Award, the NACE Fellow Honor, and was named a Fellow of the American Institute of Chemical Engineers and the Materials Technology Institute. He has served as chairman of ASTM Committee G-1 for four years. He also served on and chaired the ASTM Committee on Publications and the ASTM Board of Directors, and chaired the Finance and Audit Committee. He has also served on and chaired the Board of Directors of the Materials Technology Institute. He has 12 U.S. patents, 96 publications, and has co-edited eight books.

HARVEY P. HACK Dr. Hack is an Advisory Engineer for Northrop Grumman Corporation, where he does materials selection and corrosion control for underwater vehicles and systems for the Department of Defense. He received his B.S. and M.S. from Carnegie-Mellon University, and his Ph.D. in Metallurgy from The Pennsylvania State University. He is the recipient of the ASTM International Award of Merit, and is past Chairman of the Board of Directors of ASTM International. Dr. Hack has received the Distinguished Service Award from NACE International, the Francis L. LaQue Memorial Award from ASTM Committee G-1 on Corrosion of Metals, and the Francis L. LaQue Award from the Sea Horse Institute. He is a NACE Corrosion Specialist, Cathodic Protection Specialist, and Coatings Inspector, a Fellow of NACE International, ASTM International, the Washington Academy of Sciences, and the Institute of Corrosion in the United Kingdom, and is a Registered Professional Engineer in Maryland. Dr. Hack is the Associate Editor for the Materials Performance and Characterization section of the *Journal of ASTM International (JAI)*, is on the Materials Advisory Board for the National Air and Space Museum of the Smithsonian Institution, and is a past President of the Council of Engineering and Scientific Specialty Boards. Dr. Hack has approximately 70 publications and is the author, editor, or major con-tributor to five books. He is the author of a regular column on corrosion in *Underwater Magazine*.

EDWARD L. HIBNER is a Senior Metallurgist and Code Manager at Special Metals Corporation, formerly Inco Alloys International, in Huntington, West Virginia. He received his B.S. in Chemistry from Marshall University and in Metallurgy from the University of Cincinnati. He is the recipient of the ASTM Award of Merit, the ASTM Committee G-1 Francis L. LaQue Memorial Award, the ASTM Committee G-1 Certificate of Appreciation, and the NACE Fellow Award, and is currently Vice-Chairman and the Editorial Review Chairman of ASTM Committee G-1 on Corrosion of Metals. He has served as Chairman and as Trustee of the West Virginia Section of NACE International and is currently serving on the NACE MR0175/ ISO 15156 Maintenance Panel. He has extensive experience in alloy development for chemical process, flue gas desulfurization, marine, and oil field applications. He has written widely on materials applications and corrosion topics in these fields and has four patents and 60 publications. In addition to ASTM International, he is a member of the International Desalination Association, the Society for Petroleum Engineers, ASME International, SAE International, NACE International, and the Naval Submarine League.

JOHN R. SCULLY received his B.S., M.S., and Ph.D. in Materials Science and Engineering from Johns Hopkins University. While pursuing his Ph.D., he worked at David Taylor Naval Ship R&D Center in Annapolis, Maryland in the Marine Corrosion Branch. He then joined Sandia National Laboratory after a term as a Visiting Scientist at AT&T Bell Laboratories. In 1990, he joined the faculty of the Department of Materials Science and Engineering at the University of Virginia and is a full professor and co-directs the Center for Electrochemical Science and Engineering. Professor Scully received the 1985 A. B. Campbell Young Author Award from NACE. He has also been selected as a National Science Foundation Young Investigator, and has received the H. H. Uhlig Award from NACE and the William Blum Award from the Electrochemical Society. Professor Scully has published over 100 technical papers and edited several books on corrosion.

Reviewers

Dinesh Agarwal
Vinod Agarwala
Hira Ahluwalia
Paul Aimone
George Andersen
Frank Ansuini
Peter Ault
Denise Aylor
Robert Baboian
Brian Baker
Milan Bartos
Neal Berke
Thomas Britton
C. Sean Brossia
Rudolph G. Buchheit
Kenneth Budinski
James Bushman
Paul Brewer
Julie Brown
Kirk Bundy
Gustavo Cragnolino
Lee Craig
Sheldon Dean
Terry DeBold
Stephen Dexter
George DiBari
Jeffrey Didas
Charles Dillon
Marcia Domack
George Downs
Dave Duquette
K. Daniel Efird
Nathan Eisinger
Peter Elliott
David Enos
Ed Escalante
John Fitzgerald
Anna Fraker
Gerald Frankel
Jim Gossett
Richard Granata
Harvey Hack
William Hartt
Gardner Haynes
George Hays
Edward Hibner
Stanley Hirozawa
F. Galen Hodge
Alfred Hopkins
William Jarosinski
James Jenkins
Denny Jones
Russell Jones
Robert Kain
Mike Katcher
Robert Kelly
Gerhardus Koch
Simeon Krumbein
Paul Labine
Herbert Lawson
Jason Lee
Daoming Li
Brenda Little
Daryl Little
Frank Lutze
Florian Mansfeld
Charles Marsh
James Martin
Peter Mayer
Joseph Menke
Jean-Marc Meyer
Harold Michels
Tom Mills
James Moran
Patrick Morris
Max Moskal
Jim Myers
James Noel
Sankara Papavinasam
Frederick Pettit
Bopinder Phull
Robert Puyear
David Reiser
Pierre Roberge
Paul Rothman
Ken St. John
Alberto Sagues
Stuart Saunders
John Schemel
George Schick
John Scully
K. Anthony Selby
David Shifler
Tetyana Shmyreva
David Silverman
J. Douglas Sinclair
Raymund Singleton
Joseph Slusser
Gaylord Smith
John Snodgrass
Donald Snyder
Narasi Sridhar
Sridhar Srinivasan
Anthony Stavros
T. J. Summerson
William Tillis
Herbert Townsend
Hector Videla
Yash Virmani
George Waid
Robert Wei
Paul Whitcraft
Ian Wright
George Young
Walter Young

Foreword

THE REVISED PUBLICATION, *Corrosion Tests and Standards: Application and Interpretation*, is sponsored by ASTM Committee G1 on Corrosion of Metals and edited by Robert Baboian, RB Corrosion Service. Section editors include Robert Baboian, Sheldon W. Dean, Dean Corrosion Technology, Harvey P. Hack, Northrup Grumman Corporation, Edward Hibner, Special Metals Corporation, and John R. Scully, University of Virginia. This is the second edition of Manual 20 in the ASTM Manual series.

Preface

CORROSION CONTINUES to be a problem of worldwide importance. The second edition of this manual has been prepared and published to address this form of degradation. Corrosion is often neglected, but it seriously impacts our economy, jeopardizes human health and safety, and impedes technological progress. The most important factors in addressing corrosion and its control are: (1) recognizing and understanding the mechanisms, (2) developing solutions to the problems, and (3) implementing those solutions. Corrosion tests and standards are very significant in addressing each of these factors. Therefore, this manual includes guidelines for recognizing types of corrosion as well as fundamentals of testing and provides the tools required for making calculations, interpretations, and correlations. It serves as a source book of procedures, equipment, and standards used in testing.

The editor and section editors have coordinated the revision and update of this book so that most recent technologies are included in each section. In most cases, the original authors of chapters have made the revisions. In some cases, new authors needed to be chosen, or the editors performed that task. Users of the manual will find that it is an invaluable and instructive tool, as well as a source book on how to conduct corrosion tests, interpret results, and use standards.

The second edition of the manual is the result of a massive effort of planning, writing, reviewing, editing, production, and marketing. It would not have been possible without the outstanding efforts of the ASTM staff and the valuable and competent work of the editors and over 400 experts in the field that donated their time as authors and reviewers. They represent industrial, educational, and government organizations, and their contributions are greatly appreciated.

Robert Baboian
Editor

Contents

www.astm.org

ISBN 0-8031-2098-2

ASTM Stock# MNL20-2ND