Handbook of Materials Failure Analysis

With Case Studies from the Oil and Gas Industries

Edited by
Abdel Salam Hamdy Makhlouf
Mahmood Aliofkhazraei

Handbook of Materials Failure Analysis With Case Studies from the Oil and Gas Industry

Edited by

Abdel Salam Hamdy Makhlouf

Mahmood Aliofkhazraei

ELSEVIER

AMSTERDAM • BOSTON • HEIDELBERG • LONDON
NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO

Butterworth-Heinemann is an imprint of Elsevier

BH

Butterworth Heinemann is an imprint of Elsevier
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, UK
225 Wyman Street, Waltham, MA 02451, USA

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress

ISBN: 978-0-08-100117-2

Printed in the United States of America

Handbook of Materials Failure Analysis With Case Studies from the Oil and Gas Industry

Contributors

Mohammed A. Al-Anezi
Saudi Aramco, Dhahran, Saudi Arabia

Tariq A. Al-Ghamdi
Saudi Aramco, Dhahran, Saudi Arabia

Saad M. Al-Muaili
Saudi Aramco, Dhahran, Saudi Arabia

Waleed L. Al-Otaibi
Saudi Aramco, Dhahran, Saudi Arabia

Julien Capelle
ENIM (LaBPS), Metz, France

Guillermina Capiel
Composite Materials, Institute of Materials Science and Technology (INTEMA), University of Mar del Plata and National Research Council, and Chemical Engineering Department, University of Mar del Plata, Mar del Plata, Argentina

Carlos Chastre
Department of Civil Engineering, FCT, Universidade NOVA de Lisboa, Lisboa, Portugal

Joaquim S. Corte
Universidade Federal do Rio de Janeiro, COPPE, Programa de Engenharia Metalúrgica e Materiais, Rio de Janeiro, Brazil

Tito L. da Silveira
TSEC Integridade Estrutural Ltda, Rio de Janeiro, Brasil

Ryuichiro Ebara
Institute of Materials Science and Technology, Fukuoka University, Fukuoka-city, Japan

Ahmed Z. Farahat
Central Metallurgical Research and Development Institute, CMRDI, Helwan, Cairo, Egypt

Pablo Fayó
Composite Materials, Institute of Materials Science and Technology (INTEMA), University of Mar del Plata and National Research Council, Mar del Plata, Argentina

Pablo Fazzini
GIE S.A., Failure Analysis Division, Mar del Plata, Argentina

Heloisa C. Furtado
Electrical Research Center, Rio de Janeiro, Brazil

Yi Gong
Department of Materials Science, Fudan University, Shanghai, China

Shokrollah Hassani
BP America Inc., Houston, TX, USA

Alexander Hudgins
Exponent, Menlo Park, California, USA

Brad James
Exponent, Menlo Park, California, USA

Hernán G. Kunert
University of Mar del Plata, and GIE S.A., Failure Analysis Division, Mar del Plata, Argentina

Chun Q. Li
Royal Melbourne Institute of Technology, Melbourne, Australia

Tan F. Long
UTM-MPRC Institue for Oil and Gas, Universiti Teknologi Malaysia (UTM), Skudai, Johor, Malaysia

Marco Ludovico-Marques
Barreiro School of Technology, Polytechnic Institute of Setúbal, Lavradio, Portugal

Mojtaba Mahmoodian
Royal Melbourne Institute of Technology, Melbourne, Australia

Zulkifli A. Majid
UTM-MPRC Institue for Oil and Gas, Universiti Teknologi Malaysia (UTM), Skudai, Johor, Malaysia

Abdel S.H. Makhlouf
Manufacturing and Industrial Engineering Department, College of Engineering and Computer Science, University of Texas Rio Grande Valley

Anibal A. Marquez
University of Mar del Plata, and INTEMA-CONICET, Mar del Plata, Argentina

Iain L. May
Metallurgical Consulting Services Ltd., Saskatoon, SK, Canada

Rahmat Mohsin
UTM-MPRC Institue for Oil and Gas, Universiti Teknologi Malaysia (UTM), Skudai, Johor, Malaysia

Pablo E. Montemartini
Composite Materials, Institute of Materials Science and Technology (INTEMA), University of Mar del Plata and National Research Council, and Chemical Engineering Department, University of Mar del Plata,Mar del Plata, Argentina

Seifollah Nasrazadani
Engineering Technology Department, University of North Texas, Denton, TX, USA

Antonela Orofino
Composite Materials, Institute of Materials Science and Technology (INTEMA), University of Mar del Plata and National Research Council, and Chemical Engineering Department, University of Mar del Plata, Mar del Plata, Argentina

José L. Otegui
Y-TEC (YPF—CONICET), Ensenada, Argentina

Juan M. Pardal
Universidade Federal Fluminense – Escola de Engenharia, Rua Passo da Pátria, Niterói, Rio de Janeiro, Brazil

Guy Pluvinage
ENIM (LaBPS), Metz, France

Iván U. Pérez
Universidad Industrial Santander, Bucaramanga, Colombia

Xudong Qian
Department of Civil and Environmental Engineering, National University of Singapore, Singapore

Carlos Rubio-González
Centro de Ingeniería y Desarrollo Industrial, Querétaro, México

Juan M. Salgado-López
Centro de Ingeniería y Desarrollo Industrial, Querétaro, México

Christian Schmitt
ENIM (LaBPS), Metz, France

Sérgio S.M. Tavares
Universidade Federal Fluminense – Escola de Engenharia, Rua Passo da Pátria, Niterói, Rio de Janeiro, Brazil

Gudimella V.S. Murthy
Materials Science and Technology Division, CSIR-National Metallurgical Laboratory, Jamshedpur, Jharkhand, India

Zhen-Guo Yang
Department of Materials Science, Fudan University, Shanghai, China

Xiao-Hua Zhu
School of Mechanical Engineering, Southwest Petroleum University, Chengdu, China

Preface

Failure analysis and prevention are important issues for all engineering materials and industrial structures. One of the most important engineering fields which plays an essential role in failure analysis is Materials Engineering. Whether the failure happens in service or during the production process (manufacturing defects), failure analysis must be performed in order to prevent it from happening again in future. Another important factor which must be precisely investigated is to determine whether or not the metallic components and structures are being used well.

There have been several reports of catastrophic accidents in the Oil and Gas industry in countries including the United Kingdom, Kuwait, the United States of America, Venezuela, etc. Most, if not all of these accidents, were due to materials failure and were thought to be the cause of a number of workers being killed, in addition to the environmental crises. For instance, in 1993, a natural gas pipeline running along a highway in Venezuela, exploded. The rapid combustion of the spreading gas caused a hellish situation that lead to the deaths of at least 50 people. It should be noted that a lot of factors, including bad design, improper manufacturing, low-grade raw materials in the pipe production, improper joining of the pipes and/or corrosion, can be the cause of such incidents.

This handbook covers analysis of materials failure in the Oil and Gas industry, where a single failure can result in devastating consequences for people, wildlife, the environment, and the economy of a region. The book combines introductory sections on failure analysis with numerous real-world case studies of pipelines and other types of materials failure in the Oil and Gas industry, including joint failure, leakage in crude oil storage tanks, failure of glass fiber-reinforced epoxy pipes, and failure of stainless steel components in offshore platforms, amongst others.

This handbook contains many failure real-world cases and case studies covering a wide spectrum of materials failure related to petroleum, petrochemicals, oil, and gas applications. The editors thank all the contributors for their excellent chapter contributions to this handbook, and for their hard work and patience during preparation, and production of the handbook. We sincerely hope that the publication of this handbook will help people from Industry and Academia to get the maximum benefits from the experience contained in the published chapters.

Summer 2015
Abdel Salam Hamdy Makhlouf
Mahmood Aliofkhazraei

Contents