Handbook of Materials Failure Analysis

With Case Studies from the Chemical, Concrete, and Power Industries

Edited by
Abdel Salam Hamdy Makhlouf
Mahmood Aliofkhazraei

B
H

Handbook of Materials Failure Analysis

With Case Studies from the Chemical, Concrete, and Power Industries

Edited by
Abdel Salam Hamdy Makhlouf and Mahmood Aliofkhazraei

This handbook covers the most common cases of failure and their investigation, analysis, and possible remedy in the chemicals, concrete, and power industries.

- Introduces readers to modern analytical techniques in materials failure analysis
- Combines foundational knowledge with current research on the latest developments and innovations in the field
- Includes many compelling case studies of materials failure in chemical processing plants, concrete structures, and power generation systems

About the handbook:

This handbook provides an in-depth examination of materials failure in specific situations, a vital component in both developing and engineering new solutions. It covers analysis of materials failure in the chemical, power, and structures arenas, where the failure of a single component can result in devastating consequences and costs. Material defects, mechanical failure as a result of improper design, corrosion, surface fracture, and other failure mechanisms are described in the context of real-world case studies involving steam generators, boiler tubes, gas turbine blades, welded structures, chemical conversion reactors, and more. This book is an indispensable reference for engineers and scientists studying the mechanisms of failure in these fields.

Abdel Salam Hamdy Makhlouf is a Professor in the Department of Manufacturing Engineering, College of Engineering and Computer Science, University of Texas Pan-American, USA.

Mahmood Aliofkhazraei is an Assistant Professor in the Department of Materials Science at the Tarbiat Modares University. He is an expert in the field of coatings and corrosion science.

Engineering/Materials Science

ISBN 978-0-08-100116-5

9 780081 001165

ELSEVIER

B H

Butterworth-Heinemann
An imprint of Elsevier
store.elsevier.com

Handbook of Materials Failure Analysis

With Case Studies from the Chemical, Concrete, and Power Idustries

Makhlouf
Aliofkhazraei
Editors

B|H

Handbook of Materials Failure Analysis With Case Studies from the Chemicals, Concrete, and Power Industries

Edited by

Abdel Salam Hamdy Makhlouf

Mahmood Aliofkhazraei

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

ELSEVIER

Butterworth-Heinemann is an imprint of Elsevier

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

Notices

Knowledge and best practice in this field are constantly changing. As new research and experience broaden our understanding, changes in research methods, professional practices, or medical treatment may become necessary.

Practitioners and researchers must always rely on their own experience and knowledge in evaluating and using any information, methods, compounds, or experiments described herein. In using such information or methods they should be mindful of their own safety and the safety of others, including parties for whom they have a professional responsibility.

To the fullest extent of the law, neither the Publisher nor the authors, contributors, or editors, assume any liability for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions, or ideas contained in the material herein.

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: 978-0-08-100116-5

Handbook of Materials Failure Analysis With Case Studies from the Chemicals, Concrete, and Power Industries

Contributors

Mario Attard
The University of New South Wales, Sydney, New South Wales, Australia

Seyed B. Behravesh
Fatigue and Stress Analysis Laboratory, Mechanical and Mechatronics Engineering Department, University of Waterloo, Waterloo, ON, Canada

Karima Bouzelha
Department of Civil Engineering, University of Mouloud Mammeri, Tizi Ouzou, Algeria

Alaa Chateauneuf
Polytech Clermont Ferrand, University Blaise Pascal, Clermont Ferrand, France

Kashif M. Deen
Corrosion Control Research Cell, Department of Metallurgy & Materials Engineering, CEET, University of the Punjab, Lahore, Pakistan

Mohamed R. El-Koussy
Department of Metallurgical Engineering, Cairo University, Giza, Egypt

Iman El-Mahallawi
Department of Metallurgical Engineering, Cairo University, Giza, Egypt

Mohamed El-Saady
Department of Metallurgical Engineering, Cairo University, Giza, Egypt

Samuel Frimpong
University of Missouri-Rolla, Rolla, MO, USA

Eugenio Guglielmino
Department of Electronic Engineering, Chemistry and Industrial Engineering, University of Messina, Messina, Italy

Hocine Hammoum
Department of Civil Engineering, University of Mouloud Mammeri, Tizi Ouzou, Algeria

Elfaitori Ibrahim
Fatigue and Stress Analysis Laboratory, Mechanical and Mechatronics Engineering Department, University of Waterloo, Waterloo, ON, Canada

Hamid Jahed
Fatigue and Stress Analysis Laboratory, Mechanical and Mechatronics Engineering Department, University of Waterloo, Waterloo, ON, Canada

Sakdirat Kaewunruen
Birmingham Centre for Railway Research and Education, The University of Birmingham, Edgbaston B15 2TT UK

Waleed Khalifa
Department of Metallurgical Engineering, Cairo University, Giza, Egypt

Ijaz H. Khan
Corrosion Control Research Cell, Department of Metallurgy & Materials Engineering, CEET, and Institute of Chemical Engineering & Technology, University of the Punjab, Lahore, Pakistan

Alicja K. Krella
Institute of Fluid Flow Machinery, Polish Academy of Sciences, Gdansk, Poland

Edson D. Leonel
Department of Structural Engineering, School of Engineering of São Carlos, University of São Paulo, São Carlos, SP, Brazil, and Polytech Clermont Ferrand, University Blaise Pascal, Clermont Ferrand, France

Ying Li
Bucyrus International Inc., Houston, TX, USA

Elyson A.P. Liberati
Department of Structural Engineering, School of Engineering of São Carlos, University of São Paulo, São Carlos, SP, Brazil

William Liu
Industrial Services, SGS New Zealand Limited, Auckland, New Zealand

Katarzyna Miszta-Kruk
Department of Water Supply and Wastewater Treatment, Faculty of Environmental Engineering, Warsaw, Poland

Caio G. Nogueira
Department of Civil Engineering, São Paulo State University, Bauru, SP, Brazil

George A. Pantazopoulos
ELKEME Hellenic Research Centre for Metals S.A., Athens, Greece

Rosanna Pino
Department of Electronic Engineering, Chemistry and Industrial Engineering, University of Messina, Messina, Italy

Pandora P. Psyllaki
Piraeus University of Applied Sciences, Egaleo, Greece

Atanu Saha
CSIR-Central Mechanical Engineering Research Institute, Durgapur, West Bengal, India

Mahendra K. Samal
Reactor Safety Division, Bhabha Atomic Research Centre, Trombay, Mumbai, India

Chiara Servetto
IIS Service Srl, Genova, Italy

Andrea Sili
Department of Electronic Engineering, Chemistry and Industrial Engineering, University of Messina, Messina, Italy

Drifa Slimani
Department of Civil Engineering, University of Mouloud Mammeri, Tizi Ouzou, Algeria

Yong-An Tian
Beijing Sevenstar Electronics Co., Beijing, China

Minh Vu
Sydney Trains, New South Wales, Australia

Seong-woo Woo
Korea Testing Co., Daejeon City, South Korea

Preface

Failure in different industries can happen in segments of the machines when dynamic loading occurs. When you think about fatigue, you may think of an aerial ladder, the crankshaft of an automobile, or the wing of a plane. For failure analysis of the segments structure, we need mechanical examinations. For example, to predict the lifetime of a spring of a garage door, it should be clear that how much load is applied to the spring. Also, it should be clear how many times this force is applied, for example over a period of one year, on the spring. Using analytical methods and computer modeling methods, it can be predicted after how many cycles the fatigue phenomenon will occur in the spring. After comparison between the results of the fatigue test and the computer modeling, the validity of the model can be investigated. Using fractography, it can be made clear whether or not a fracture happened due to the fatigue. Fractography is the act of investigating the fracture surface, using a microscope.

This handbook provides an in-depth examination of materials failure in specific situations, a vital component in both developing and engineering new solutions. It covers analysis of materials failure in the areas of chemicals, power, and structures, wherein the failure of a single component can result in devastating consequences and costs. Material defects, mechanical failure as a result of improper design, corrosion, surface fracture, and other failure mechanisms, are described in the context of real-world case studies involving steam generators, boiler tubes, gas turbine blades, welded structures, chemical conversion reactors, and more. This book is an indispensable reference for engineers and scientists studying the mechanisms of failure in these fields.

This handbook contains many real-world failure cases and case studies covering a wide spectrum of materials failure related to chemicals, concrete, and power 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