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Introduction

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Foreword

This 2002 edition of *Failure Analysis and Prevention* is the outcome from the devoted efforts of volunteer editors, authors, and reviewers, who have helped organize and develop this revised Volume 11 of the *ASM Handbook* series. This publication would not have been possible without their vision and dedicated efforts in the ongoing improvement of engineering knowledge and education through the analysis, understanding, and prevention of failure.

As noted in the Preface, the authors and editors assembled this Volume with several broad themes in mind. The nature of failure is complex, varied, and unanticipated. Its prevention can also be multifaceted and varied. In this way, failure analysts are not only specialists, but also educators who help others become aware of the root cause(s) of failure. This requires a clear understanding of the many stages in the life of a part from design and manufacturing to anticipated service, inspection, and maintenance. It also involves a host of tools and techniques for effective planning and implementation of a failure investigation.

Thus, failure analysis and prevention can be a complex multidisciplinary activity that requires broad knowledge in design, manufacturing, mechanics, materials, and testing. The editors and authors have tackled this complex nature of failure analysis and prevention in an updated volume that is, in many respects, an all-new volume. This new edition contains over 50 new articles with expanded coverage on the four basic types of failures (deformation, fracture, corrosion, and wear) and the variety of tools and techniques for effective planning, organization, implementation, and reliable conclusion of a failure investigation through proper interpretation of information.

We would like to extend our thanks to the devoted community of volunteers who have helped organize and develop this 2002 edition of *Failure Analysis and Prevention*. The editors, authors, and reviewers are to be commended for their fine contributions on a vital topic for all engineering disciplines, in the very best of tradition of the Handbook series. We especially thank Bill Becker, Roch Shipley, Debbie Aliya, Dan Benac, Larry Hanke, Jeff Hawk, Steve McDanel, Richard McSwain, Ron Parrington, Jim Scutti, Aaron Tanzer, and Richard Wilson. This publication would not have been possible without their vision, knowledge, and efforts.

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Preface

Welcome to the new edition of *ASM Handbook*, Volume 11, *Failure Analysis and Prevention*.

Theme and Purpose of this Volume. The authors and editors assembled this Volume with several broad themes in mind. First, the most important goal of failure analysis is to decrease the occurrence of component failures through the understanding of the root cause for failure. Experienced failure analysts are often frustrated when,

despite extensive engineering research, investigations, and failure analysis reports, the same types of failures occur again and again. When the root cause has been identified as defective global design rather than abuse or misuse, product quality and reliability is improved.

The failure analyst should strive to uncover the underlying or root (technical) cause of the failure. The fact that a specific component appears to have failed in some way does not automatically mean that the component itself is defective. The problem may lie in the way the component was used, inspected, or maintained. If it is truly defective, then the analysis should determine whether the defect originates in design, manufacture (fabrication and assembly), material selection/processing, or unexpected service environment.

This Volume provides a framework for investigating the above issues. In addition to sections devoted to design and manufacture, there are also sections on failures that occur through fracture, corrosion, and wear, as well as an article on failure through deformation. This Volume is also an attempt to address the principles, tools, techniques, and procedures necessary to plan, organize, and conduct a thorough investigation. Not every failure investigation is the same, and a failure root-cause analysis is more than a microstructural examination, a stress analysis, or a chemical corrosion analysis. All of these disciplines, as well as others, may be required to reach a root cause conclusion.

No single volume, no matter how comprehensive, can present all the information that may potentially be needed. The emphasis of this Volume is on general principles with the widest applicability to situations that the reader is likely to encounter. References and sources of further information are provided throughout. While some common types of components or equipment may be included in some detail, not every type of machine can be treated. The reader is encouraged, and in fact urged, to pursue additional sources of information so as to understand the function and history of the component, machine, or system that is under investigation.

Audience. One of the challenges in preparing a work of this type is the diversity of readership. Some readers are students and other novices who may be confronted with a failed part for the first time. They may be looking to the Handbook for guidance on where to start their analysis. Other readers are experienced practitioners, using the Handbook to verify or clarify a critical detail in their analysis. Thus, the contents of this Volume include the essential basics of failure analysis, as well as more advanced discussions from a research perspective.

The discussions of fracture mechanisms are an example of this approach to Handbook organization. The articles “Overload Failures” and “Fatigue Failures” are good starting points for readers wishing to begin their study of fracture. Examination of the fracture surface (when failure did result in fracture) at both the macro and micro scale provides considerable information pertinent to a failure investigation. This subject is introduced in the article “Overload Failures” with some discussion of the mechanisms that may be involved.

For some readers, these may be sufficient, if all they need is to identify the basic fracture mechanism. However, further study can sometimes allow the analyst to learn more about the circumstances of a fracture. Unfortunately, there are few instances in which a single fractographic feature is definitive in identifying a root cause (and to distinguish between abuse and defective design). Casual examination may not distinguish between fine details caused by different fracture processes. Consequently, a detailed study of the fracture surface at both the macroscale and microscale is helpful and may be critical in obtaining a root cause conclusion. The reader who desires a more detailed appreciation and thorough understanding should continue with the article “Fracture Appearance and Mechanisms of Deformation and Fracture” and the article “Stress Analysis and Fracture Mechanics.” These articles introduce quantitative means to relate the fracture process to material properties and, therefore, are critical to distinguishing between abuse or misuse and inadequate quality. Finally, the article “Mechanisms and Appearances of Ductile and Brittle Fracture in Metals” provides a still more in-depth treatment on the detailed appearances at both the macroscale and microscale, with the intent of extracting the maximum possible information for root-cause failure analysis.

Differences of Opinion. Controversy is, perhaps, inherent in the very nature of failure analysis. If anything, that is even truer today when real or perceived failures are the subject of litigation. The authors have integrated thoughts on legal considerations into many of the articles. However, nothing here should be taken as legal advice. Those who are concerned regarding legal implications should consult competent counsel.

Furthermore, as every circumstance is somewhat unique, the Handbook should be used with care and should not be the sole source of information when critical decisions are to be made. Most articles include extensive references, which should be reviewed if further information is required.

The authors present analyses and interpretations based on scientific principles and experience. All of the articles have been reviewed and edited. However, there can be and still are differences of opinion among failure analysts regarding some issues. It is up to the reader to determine whether the information presented is

applicable and helpful in a particular situation. Experienced analysts should be consulted if there is any doubt. Despite the best efforts of the authors, reviewers, and editors, the reader might find an area that could be improved. If so, please bring this to the attention of the ASM Editors so that your concern can be reviewed and, depending on the consensus of opinion, can be addressed in subsequent printings.

Collaborative Effort. This Volume reflects the efforts of many people. Except for ASM staff, all are volunteers. Many of the volunteers are fully employed and contributed their personal time to the project. Neither they nor their employers receive any compensation for their efforts, except for the satisfaction that accrues from being able to share what they have learned, prevent failures, and contribute to safer, more reliable products. The names of the authors, editors, reviewers, and ASM staff are acknowledged individually elsewhere in this Volume and are too numerous to list here. However, ASM Editor Steven Lampman does deserve special mention for his commitment, dedication, and patience, without which this Volume would not have become a reality.

It has been most enjoyable and professionally rewarding to work with all who were involved in this effort. On behalf of ASM and the readers of this Handbook, we express our appreciation to all for the time and effort expended and for their willingness to share their knowledge and lessons derived from experience. Many of the contributors have established national and international reputations in their respective fields. More than any words of appreciation in a Preface such as this, however, it is our hope that the Handbook itself will be a most fitting tribute to all participants, both now and into the future.

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Conversion to Electronic Files

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ASM International staff who oversaw the conversion of the Volume to electronic files were Sally Fahrenholz-Mann and Sue Hess. The electronic version was prepared under the direction of Stanley Theobald, Managing Director.

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This book is a collective effort involving hundreds of technical specialists. It brings together a wealth of information from worldwide sources to help scientists, engineers, and technicians solve current and long-range problems.

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