Introduction to the

Principles of Materials Evaluation

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Preface

This book was developed from an introductory undergraduate course in nondestructive testing and materials evaluation that has been offered for many years at Iowa State University. It deals with the basic concepts of materials evaluation and adopts the viewpoint that the underlying principle behind all materials evaluation methods is the interaction of energy of some type with a material. In other words, in order to find out anything about a material, we need to interact with it in some way, and this must come in the form of one or more types of energy. The condition of the material can then be deduced from the resulting relationship between the form of the energy input and the form of the output. This means that materials evaluation techniques can be classified systematically in terms of the main divisions of classical phenomenology: mechanics, heat, light, sound, electricity, magnetism, and radiation.

The book begins by considering the various physical properties of materials that may be of interest for materials evaluation and the means for determining these properties. We look at the various types of energy: mechanical, acoustic, thermal, optical, electrical, magnetic, and radiative. We then study how each of these types of energy provides the basis for measurements that can be made on any material. The results of these measurements are simply relationships between the input energy and the output energy. These relationships are determined by the properties and condition of the material and so, by inference, can be used to evaluate the condition of the material. The role of the material in determining the relationship through its response to the energy is therefore central to our understanding. The interpretation of the results is usually based on empirical knowledge or on models, which comprise mathematical equations with adjustable parameters that can be used to describe practical situations and, less often, on first principles theories, which rely more on basic physical laws. Finally, we look at technological applications, including the important considerations of destructive vs. nondestructive testing for flaws, the concept of materials characterization in which the intrinsic materials properties are studied before flaws appear, the need for *in situ* measurements and, finally, the recurring issue of plant life extension and retirement for cause.

The underlying concept is to examine the physical bases for materials evaluation, rather than just presenting the subject as a set of empirical techniques. This is achieved by emphasizing common principles in materials evaluation procedures and by looking at the fundamental physics of materials evaluation in terms of energy interacting with a material in a controlled way. This can be approached by considering that the relationship between energy

input and output is determined by the material condition alone. Therefore, any information that can be extracted about the condition of the material comes from these relationships. In materials evaluation, the task becomes understanding how we do this in various cases and extracting what is common in each of these cases.

David Jiles

Acknowledgments

I am grateful to the authors and publishers for permission to reproduce the following figures that appear in this book:

Figure 2.3 J.R. Davis (Editor), *Metals Handbook*, Desk Edition, 2nd Edition, ASM International, Materials Park, Ohio, 1998.

Figure 7.10 J.R. Davis, (Editor), *ASM Handbook*, Desk Edition, 2nd Edition, ASM International, Materials Park, Ohio, 1998.

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Figure 8.15 H.J. Rindorf, Acoustic Emission Source Location in Theory and in Practice, *Brüel & Kjær Technical Review*, No. 2, 1981.

Figure 8.16 H.J. Rindorf, Acoustic Emission Source Location in Theory and in Practice, *Brüel & Kjær Technical Review*, No. 2, 1981.

Figure 10.10 W. Lord, *IEEE Transactions on Magnetics*, 19, 2437, 1983.

Figure 11.4 L. Cartz, *Nondestructive Testing*, ASM International, Materials Park, Ohio, 1995.

Figure 11.6 *Nondestructive Testing*, Vol. 03.03, Section 3, ASTM Standards, American Society for Testing and Materials, Philadelphia, Pennsylvania.

Figure 11.7 *Nondestructive Testing*, Vol. 03.03, Section 3, ASTM Standards, American Society for Testing and Materials, Philadelphia, Pennsylvania.

Figure 11.8 *Nondestructive Testing*, Vol. 03.03, Section 3, ASTM Standards, American Society for Testing and Materials, Philadelphia, Pennsylvania.

Figure 14.5 S. N. Rajesh, L. Udpa, and S. S. Udpa, Review of Progress in Quantitative Nondestructive Evaluation, D. O. Thompson and D. E. Chimenti, Editors, Vol. 12B, 1993, pp. 2365–2372, Plenum, New York.

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Figure 15.4 R.H. Burkel et al., U.S. Department of Transportation, Federal Aviation Administration Report No. DOT/FAA/AR-01/96, September 2002.

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Chapter 12

1 Introduction

This chapter provides an overview of some of the considerations that go into materials evaluation and nondestructive testing. It includes the concept of materials' lifetime, whereby the degradation and eventual replacement or failure of materials are considered as normal, and a discussion of factors that can cause failure of materials. In addition to a summary of some of the most basic inspection techniques, it describes the considerations that arise when a material is found to be flawed, particularly whether the material should be replaced or whether continued operation is possible. The chapter forms a foundation for the ideas that are presented in the following chapters of the book.

1.1 FUNDAMENTALS OF MATERIALS EVALUATION AND THE CONCEPT OF LIFETIME OF MATERIALS

Perhaps the most important concept in materials evaluation and nondestructive testing is that materials change with time and that these changes need to be considered as normal. This concept is somewhat different from the traditional viewpoint of materials science in which a material is fabricated and that is the end of the process, almost as if the material will now remain the same indefinitely, unless something unexpected happens to it.

In practice, when a material is fabricated for a particular application, it is then used under certain operating conditions and, after service exposure, the material is not the same as when it began life. The changes usually arise in the form of degradation of the materials' properties and, if this process continues, then it can eventually lead to failure. It is therefore desirable to monitor the degradation of the material, if for no other reason than to identify when failure is likely to occur.

1.1.1 Effects of Different Forms of Energy on Materials

Structural changes occur in a material as a result of prolonged exposure to high levels of different forms of energy. These changes can include residual stress (increased dislocation density), embrittlement (decrease in toughness), fatigue (tendency for failure after exposure to repeated cycling of applied stress), creep (slow flow of material under applied stress and elevated temperature leading to voids and cavities in the material), and radiation damage (accumulation of defects or migration of chemical species resulting from interactions with radiation).