Principles of the Heat Treatment of Plain Carbon and Low-Alloy STEELS

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Dedication

This book is dedicated to my wife Sue for her editing assistance with this project and my other books, and for her patience and support (usually) in my other endeavors.

Acknowledgments

I thank many researchers and organizations for allowing me to use information from their works and publications; the sources are acknowledged where the information appears in the book. I particularly acknowledge ASM International for permission to use material from many of their publications. Special appreciation is expressed to Professor George Krauss for permission to use information from his own research and that of his co-workers. Also, special appreciation is expressed to Mrs. Iris Thelning for permission to use information from *Steel and its Heat Treatment*, Butterworths, London (1975) by her late husband Karl-Erik Thelning. I also am indebted for the assistance of Veronica Flint of ASM International in editing and publishing this book. Mrs. Carla Lawerence is thanked for her patient typing of the manuscript, and Mrs. Deb Basak kindly fitted some of the data to polynomials.

Preface

In the current highly competitive field of materials, steels continue to be widely used, and of these the plain carbon and low alloy steels usually are the material of choice for structural and machine components. The purpose of this book is to provide background information on the practical physical metallurgy of the heat treatment and choice of these steels. The material presented here should be of value to engineers involved in the application of steels in manufacturing who must be aware of all aspects which provide a competitive benefit. This will be of particular interest to metallurgists and metallurgical engineers, but also to other engineers involved in the design and use of components made from steel.

Considerable information from the literature has been used to illustrate the points made, but no serious attempt has been made to convert the data to SI units. Conversion tables are given in appendices.

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Chapter 1

Introduction

The materials used in components are now highly diversified, with many applications historically reserved for steels now taken by plastics, composites and ceramics. This change has been brought about by economic factors, environmental factors (e.g., lighter weight automobiles for better gas mileage and less air pollution), and (at least certainly in the United States) by international competition. These three factors are not independent of each other.

There are, of course, many applications for which steels are still clearly the most suitable material. And there are former applications of steels which may in the future be reclaimed if the factors listed in the preceding paragraph become more favorable for the use of steels. Thus, at the present time it is especially important that the type of steel chosen for a given application, and the heat treatment given it, be critically examined in order to justify its use.

The choice of steel in general for an application, and specific steels in particular, rests not just on the cost of the starting stock material (e.g., bars, plates), which is closely related to the alloy content, but also on the cost of the heat treatment, and on the subsequent success of the manufactured component. For example, the best choice may require a more expensive steel which can be hardened with less concern about control of the cooling process in order to reduce rejections because of inadequate hardening during quenching.

The current (and future) manufacturing climate requires extremely careful consideration of the choice of steel and the design of its heat treatment. To do this requires understanding the factors that affect the response of steels to heat treatment and knowing how to use these factors in choosing the steel and in designing the heat treatment. Methods to do this have been under close scrutiny and continue to be under development.

The purpose of this book is to review current methods of examining the suitability of a given steel for an application in which the main property of concern is hardness (or strength). Some of the methods are quantitative (at least approximately) and others are correlative. Taken together, they serve as a powerful guide and method of choosing steels and designing their heat treatment. In the following chapters, a brief review of the concepts of the common method of graphically depicting the decomposition of austenite, the time-temperature-transformation (TTT) diagrams, is given first. Then the concept of hardenability is presented, and the methods of calculating hardenability from the chemical composition and the austenite grain size are reviewed. Then the heat transfer process during quenching is examined. Methods of estimating the temperature-time curve during quenching at various locations in simple shapes (e.g., bars, plates) are presented. This information, coupled with the hardenability information, allows estimating the hardness distribution which is developed by the hardening heat treatment. Tempering is reviewed since most steels require subsequent tempering (mainly for improved toughness). Austenitizing, the precursor to hardening, is covered, followed by a treatment of annealing, normalizing, martempering, austempering and intercritical heat treatment. The heat treatment of steels is being increasingly modeled with computer programs, and this is reviewed. In the last chapter, examples of the use of the material in the preceding chapters to the design of heat treatments are given.

It is assumed that the reader is familiar with the general concepts and terminology (e.g., austenite, martensite, etc.) of the heat treatment of steels. These are covered in introductory physical metallurgy and materials science books, and in specific books on heat treatment.

The first three listed here are recommended for background information on heat treatment of steels.

The last book has an excellent selection of microstructures.

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Chapter 1: Introduction

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Further Reading

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• G. Krauss *Steels: Heat Treatment and Processing Principles*, ASM International, Materials Park, Ohio (1990)

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Chapter 7: Annealing, Normalizing, Martempering, and Austempering

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Chapter 10: Illustrative Examples

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