The Engineer's Guide to Steel

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Preface

This book is for everyone who is interested in steel; but most particularly it is intended to help the engineer engaged in any aspect of steel structural design and construction, the steel supplier and purchaser, the man who works with steel. And it is intended, too, to satisfy the curiosity of the student, whether the student is taking a university or college course in metallurgy or strength of materials, or is one of that growing body of students—a man that is eager to learn about the materials he works with and the things about him.

There is no need to expound upon the common complaint that people who work with materials (designing, constructing, maintaining) know very little about the nature of the stuff they work with. The more important matter is to correct this deficiency. We believe that since the most vital of all engineering materials is steel, we should attempt to provide in one volume the information that the steel user so often asks for, or at any rate, so often needs.

Specific, factual data that are most frequently sought can be found in Part III of this book. Here we have tried not only to describe the properties and purposes of commercially important grades of steel, but to explain the reasons for certain types of behavior, certain sorts of specifications, so that a sensible appreciation may be developed of the properties and applications of commonly specified steels. Topics that are not directly, or obviously, included in specifications—machinability, wear resistance—are treated in separate chapters in this section.

However, while Part III describes the intention of specifications, the properties and the applications of commercial steels, we felt it necessary to describe our interpretation of the aims and purposes of different specifying bodies, together with brief accounts of the most important tests that these bodies call for. We have also attempted to evaluate the worth of these tests, pointing out precautions that should be observed when the test data are used. These topics, together with a chapter outlining the methods and scope of nondestructive testing (increasingly asked for in specifications or by private arrangement, or used in manufacturing control) constitute Part II.

Even this, though, is not enough for a reasonably complete understanding: if a man is to appreciate why a specification takes a particular form, if he is to know the limitations of a particular steel, the dangers, the advantages, he should surely know what steel is. Therefore in Part I we have described the metallurgy of steel to an extent that we believe to be necessary for a full appreciation of subsequent chapters. One should know how steel is made and fabricated: after all, this determines its price, and rationalizes the breadth or the peculiarities of steel specifications. And if the nature of steel—why it is what it is—is to be understood at all, then a chapter on the physical metallurgy of steel (Chapter 2) is essential. Further, since that most common fabricating technique, welding, involves vital property changes (which too often seem to baffle the engineer) a chapter on this subject has also been included in Part I. The chapters on brittle failure (Brittle Fracture and Fatigue) are incorporated because we are shocked by the extent of the ignorance that is displayed about this subject: it is, in fact, incredible that the design of so many structures still ignores the danger of brittle failure; and we deplore the unnecessary loss of life that is too often associated with the phenomenon.

While each chapter is fairly self-contained, and while each section is more completely self-contained, we hope that the book in its entirety will properly acquaint the steel user with the stuff he uses, and will answer the questions of the student. Our difficulty has been rather in deciding what to leave out than what to include: and our decisions have been reached by a combination of considerations, such as the extent to which a particular steel is used, its similarity to other products, whether (despite a small tonnage) a particular product fulfills a unique purpose. But we hope that what we have included is accurate and sufficient: if it is not, we can only ask you to tell us.

We wish to thank Mr. R. M. Scott for providing us with all the photomicrographs, most of which have been taken from the files of Hanson Paar Engineering Limited. Mr. G. R. Heffernan made many valuable suggestions to us about the presentation of Chapters 1 and 2. Mr. John Tuskey contributed his advice and criticism for Chapter 11. Mr. K. Valens supplied us with radiographs of weld defects from his files. We are most grateful for this assistance.

Acknowledgements to authors and publishers for permission to reprint figures and data from their works are made throughout the text. Here, we apologize for any omissions and hope that they will be brought to our attention.

September 1964 A. H.
Edmonton, Alberta, Canada J. G. P.

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Part I

METALLURGY OF STEEL

1

Technology of the Steel Industry

Alloys based on iron, and often containing only two or three percent of added elements, exhibit a remarkable range of properties: properties that permit them to be used for transformer cores or for cutting tools, for die steels that are used hot or for the forging that the dies form, for vessels in chemical plants or for intricate deep-drawn shapes, and—the greatest tonnage—for common structural purposes.

Of the million tons of steel that are made in the world each day (see Table 1–1), by far the largest portion is used for structural purposes (beams, reinforcing bar, plate in buildings, piling, rolling stock, ships, and pipe) and sells at a base price about six cents per pound. This introduces what is perhaps the most important quality of steel: its availability. The availability of the common metals by reduction of their oxides is graphically compared in Fig. 1–1, which shows the variation with temperature of the standard free energies of formation of the oxides for reactions involving one mole of oxygen. The least stable oxides—those at the top of the figure, having the lowest negative values for free energies of formation—are most easily reduced, and a metal may act as a reducing agent for the oxides above it. This useful presentation of thermodynamic data displays the fact that at temperatures up to 3200°F, carbon is the most economical reducing agent for all the common metals except aluminum, magnesium, and calcium. Philosophically inclined students of extractive metallurgy have drawn parallels between the scientific progress of a civilization and the most reactive metal that it commonly produced. Perhaps we should take heart from the fact that beryllium, magnesium, and calcium are familiar metals of our day.

About 5% of the earth's surface is iron, and as indicated in Fig. 1–1, iron can be reduced from its oxides with carbon at temperatures around

TABLE 1–1*

1961 World Production of Steel by Countries

(THOUSANDS OF NET TONS)

NORTH AMERICA	
United States	98,014
Canada	6,466
LATIN AMERICA	
Argentina	490
Brazil	2,970
Chile	431
Columbia	195
Cuba	20
Mexico	1,844
Peru	55
Venezuela	55
Others	33
WESTERN EUROPE (ECSC)	
Belgium-Luxembourg	12,243
France	19,400
Saar and West Germany	36,880
Italy	10,050
Netherlands	2,168
OTHER WESTERN EUROPE	
Austria	3,418
Denmark	358
Ireland	45
Finland	320
Greece	72
Norway	535
Portugal	75
Spain	2,568
Sweden	3,921
Switzerland	313
Turkey	310
United Kingdom	24,736
Yugoslavia	1,655
EASTERN EUROPE (RED BLOC)	
Bulgaria	331
Czechoslovakia	7,763
East Germany	3,748
Hungary	2,310
Poland	7,826
Rumania	2,315
U.S.S.R.	77,933
AFRICA	
Rhodesia and Nyasaland	90
Union of South Africa	2,723
Others	20
MIDDLE EAST	
Egypt	165
Israel	85
FAR EAST	
India	4,517
Japan	31,165
Pakistan	15
South Korea	25
Taiwan	150
Others	50
FAR EAST (RED BLOC)	
China	16,535
North Korea	871
OCEANIA	
Australia	4,295
Philippines	75

* By permission from American Iron and Steel Institute.

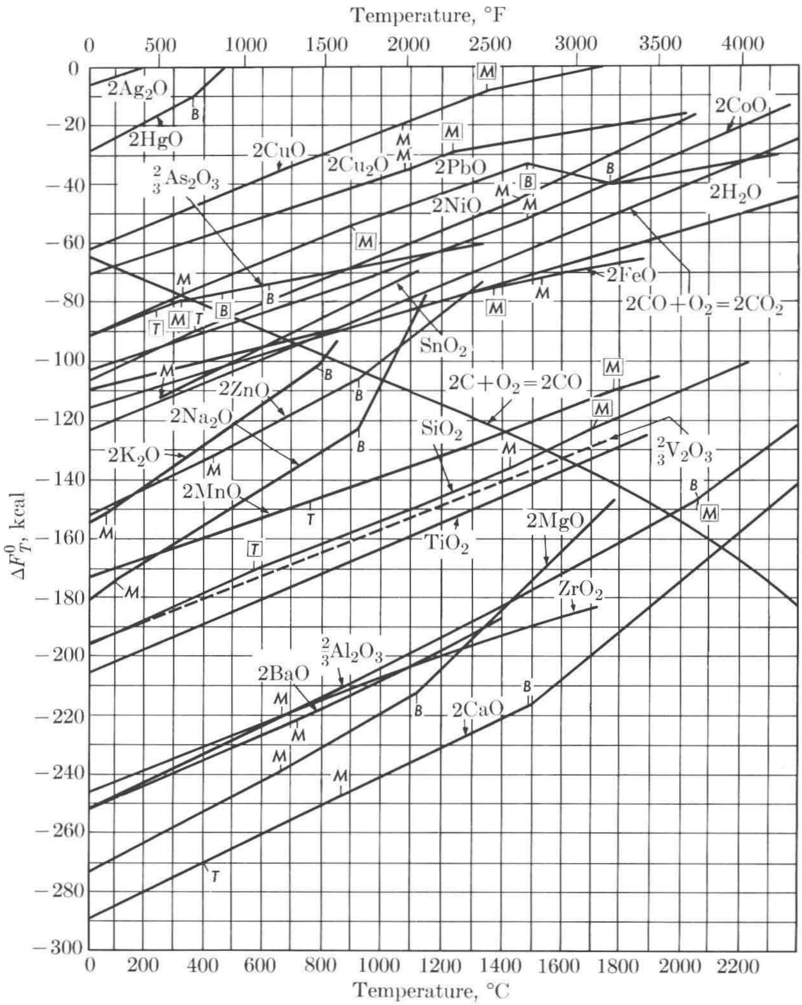

Fig. 1–1. Standard free energies of formation of metal oxides, for reactions involving one gram-mole of oxygen. M = melting point, B = boiling point, T = transition point. [By permission from C. J. Osborn, *Trans. AIME*, 100, 600 (1950).]

2900°F. In contrast, for example, silicon, which represents about 28% of the earth's surface, is not a useful engineering material, but the price of silicon cannot approach that of steel, whatever the demand. Or, another viewpoint is to interchange the availability and price of, let us say, gold with that of iron: gold at six cents a pound would not enthuse an engineer used to working with steel: its potential is restricted because the range of properties that can be induced in it is limited. There is no simple alloy

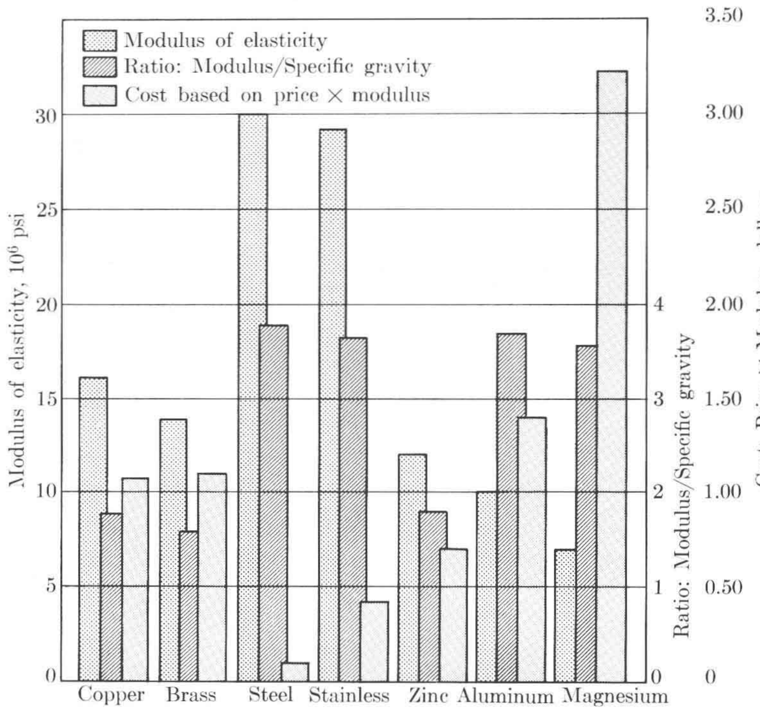

Fig. 1–2. Comparison of cost and modulus of elasticity for common structural materials. [By permission from J. R. Forrester, *Metal Progress,* 82, 97 (1962).]

of gold, so far as we know, which compares to that ubiquitous and versatile alloy of iron and carbon.

For structural applications, where a high modulus of elasticity is important, the comparison of cost × modulus presented in Fig. 1–2, clearly establishes the superiority of steel. In this connection it is interesting to note that among the more common metals, the ferrous materials have by far the highest moduli of elasticity.

Perhaps most remarkable of all is the fact that it is difficult to make iron completely free from carbon but it is comparatively simple to control the carbon content between 0.1 and 4%. While very high-purity iron has a tensile strength of 10,000 to 20,000 psi, and cannot be heat-treated to increase this figure, iron containing about 0.7% carbon may be heat-treated to a tensile strength about 400,000 psi, although it must be admitted that other alloying elements are inevitably or purposefully present. However, the valuable fact remains that carbon originally found itself in steels not through a sophisticated scientific deduction nor an empirical try-it-and-see development program. It was there because it got there during the manufacturing process. Other elements are inevitably present, too, and because the properties of steel depend on these associated elements as well as on the intentionally added ones, it is well to understand for what reasons they are necessarily present. There is another good reason for appreciating this, too: it is embarrassing both to the engineer and to the steel supplier when a specified material simply cannot be made by accepted commercial processes.

Steel is made from iron which, in turn, is reduced from iron oxide. The iron oxide minerals are associated with other metallic oxides which are partially or wholly reduced during the ironmaking processes and are dissolved in the melt. They could conceivably be almost completely removed—but not to permit the production of steel at six cents per pound. Fig. 1–3 shows a flowchart of the steelmaking process. Production of the particular grade of steel to be poured into the ingots involves the following three processes.

Reduction Process

Iron oxides are reduced with carbon in a blast furnace, which is the principal engineering plant for the production of iron. As previously mentioned, associated minor constituents except calcium, magnesium, and aluminum are concurrently reduced. Liquid iron at steelmaking temperatures, around 2900°F, is almost a universal solvent. Therefore, the liquid product of blast furnaces is a ferrous solution of carbon and all the elements introduced in the ore, the coke, and the limestone, and which, according to Fig. 1–1, can be reduced by carbon at temperatures up to 3200°F.

Oxidation Process

This operation primarily involves the removal, by reaction with oxygen, of carbon dissolved in the pig iron and of those metallic elements which can be oxidized in preference to iron. The main mechanical devices wherein this is accomplished are the basic open hearth, the basic oxygen converter, the electric furnace, and the bessemer converter.

Deoxidation Process

Dissolved oxygen in the melt, arising from the oxidation process, must be reduced to a level at which undesirable reactions with carbon, manganese, and silicon will not occur, especially during the teeming and solidification stages. Deoxidation is accomplished by introduction into

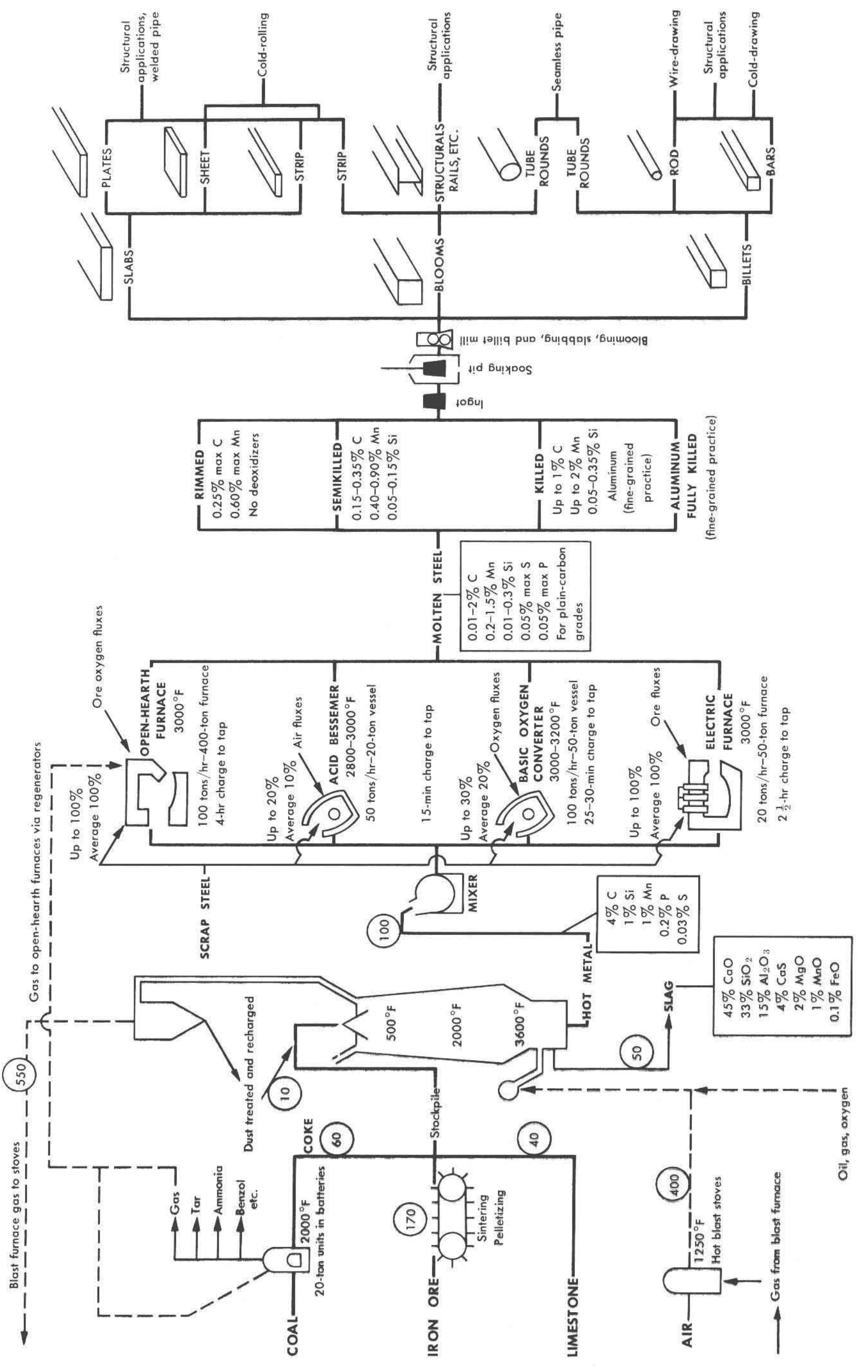

Fig. 1–3. Flow chart of steelmaking process. [Note: Circled figures are tons per hour, based on 100 tons per hour hot metal produced. Steelmaking tonnages are for typical units.]