Contents

Preface vii

About the Author ix

Introduction xi

The Earliest Discoveries xi
The Ages of Man xii
The Naming and Numbering of Metals xiii
What Is a Metal? xiii
The Nature of Metals xv
The Development of Alloys xv

The Dictionary 1

Appendix 1 Metals History Timeline 278

Appendix 2 Bibliography 327

Appendix 3 Properties and Conversion Tables 329
Table 1 Periodic table of the Elements 329
Table 2 Physical properties of the elements 330
Table 3 Density of metals and alloys 336
Table 4 Linear thermal expansion of metals and alloys 339
Table 5 Thermal conductivity of metals and alloys 341
Table 6 Electrical conductivity and resistivity of metals and alloys 343
Table 7 Vapor pressures of the metallic elements 345
Table 8 Standard reduction potentials of metals 346
Table 9 The 45 most abundant elements in the earth's crust 346
Table 10 The electrochemical series 347
Table 11 Metal melting range and color scale 348
Table 12 Predominant flame colors of metallic elements 349
Table 13 Average percentage of metals in igneous rocks 349
Table 14 Temperature conversion 350
Table 15 Metric stress or pressure conversions 354
Table 16 Metric energy conversions 356
Table 17 Metric length and weight conversion factors 356
Table 18 Conversion of inches to millimeters 357
Table 19 Conversion of millimeters to inches 357
Preface

The story of metals is undeniably entwined with the history of humanity, as evidenced by the division of the ages by the well-known Stone Age, Bronze Age, Iron Age, and what some have called the Steel Age and the Stainless Steel Age. Metals, more than any other material, have had the greatest influence on the development of civilization from prehistoric times.

Metals were used for horseshoes, tools, knives, cook pots, cups and plates, nails, chains, cannon balls, and coins. That was when metals were made in small enough crucibles so that one or two men could lift them for casting. In the middle of the 19th century, Henry Bessemer showed how to make steel by the ton so that a long piece of metal could be made into a pipe, sheet, wire, or beam, leading eventually to the manufacture of machinery, ships, refineries, power plants, skyscrapers, and airplanes.

Every metal has its own exciting story that tells of its unique properties, the obstacles encountered in producing it, and its advantages and special uses. Metals are all around us and, for the most part, are taken for granted. But what would we do without that tiny amount of silicon in every computer chip produced, or the stainless steel in the utensils on our kitchen tables?

The Dictionary of Metals includes descriptions of metals and terms relating to metals. It also includes a considerable amount of the history, starting with the seven metals of antiquity. Each of the 73 metallic elements has a discussion that includes the discoverer and date, the naming of the metal and its meaning, major applications, and the significance of discovery. Charts show their physical properties. An appendix includes a timeline of important events in the history of metals and metallurgy.

In addition to the basic metals, hundreds of alloys are described, as well as common names such as mild steel, cartridge brass, wrought iron, sterling silver, Muntz metal, Alclad, rare earth metal, metalloids, and killed steel.

Most of the elements in the periodic table of chemical elements are classified as metals. In fact, 73 of the 92 naturally-occurring elements are metals. Metals have been divided into two classes, with ferrous implying all metals and alloys that are principally iron, while the nonferrous consists of all others. This seemingly one-sided division is not so strange when it is realized that about half of all of the alloys are ferrous, of which most are some type of steel. In all, it is estimated that there are at least 25,000 alloys.

Because each metallic element consists of atoms containing different numbers of subatomic particles, it follows that each metal must be different from all the others, having properties that make each metal unique. The properties of
metals are classified as physical and mechanical. The physical properties are the basic characteristics, while the mechanical properties are those that can be determined by deforming or breaking a specimen.

The Dictionary of Metals was compiled in a comprehensive manner, and as such it brings together terms from dozens of authoritative publications, introducing new terms and preserving the old.

I wish to acknowledge the following staff of ASM International for their work on this book: Vicki Burt, Scott Henry, Steve Lampman, and Amy Nolan in the Content Department, and Kelly Sukol and Madrid Tramble in the Production Department. I especially thank my son, Bruce Warren Cobb, and Evelyn Dorothy Roberts for assistance with typing; to my cousin, Anne Cobb Moore for assistance with translation; to Susan Frederick for historical research at the public library in Exton, Pennsylvania; and my wife Joan Inman Cobb for proofreading, construction and many suggestions.

This book includes both original work and carefully selected terms from the ASM Materials Engineering Dictionary, the ASM Handbook series, and other references as listed in the Bibliography. Terms are supplemented by illustrations and tables, and Technical Notes provide concise overviews of the properties, compositions, and applications of selected metals, and direct readers to more detailed information.

The book will be of primary interest to engineers, metallurgists, chemists, professors of Materials Engineering, technicians, librarians, and historians. For these and other interested audiences, in addition to meeting the obvious need of having metallurgical definitions at one’s fingertips, it was written with the intent of being an engaging volume that actually can be read as a book.

Harold M. Cobb
About the Author

Harold M. Cobb graduated from Yale University in 1943 with a degree in metallurgical engineering. He has had a long and varied metallurgical career that began with 22 years at companies that produced aircraft gas turbines, propeller blades, helicopters, and fuel elements for nuclear submarines.

He then was on the staff of the American Society for Testing and Materials (ASTM) for 18 years as Group Manager of the Metals Division, where he was an ex-officio member of 12 metals committees. He was a member of ISO Committee TC 17 on Steel and Secretary of Subcommittee 12 on Steel Sheet for 15 years.

In 1970, Cobb was a principal developer of the Unified Numbering System (UNS) for metals and alloys. He developed the individual numbering systems for three categories: Miscellaneous Steels, the K series; Cast Steels, the J series; and Steels Specified by Mechanical Properties, the D series. He also became the number assigner for the D and K series of steels and is still responsible for that activity.

For many years he has been an editorial consultant for the ASTM/SAE publication *Metals and Alloys in the Unified Numbering System (UNS)*. Cobb created and now maintains the Index of Common Names and Trade Names of that book, an index that has grown to approximately 20,000 entries.

He has edited 24 books on metals, and in 2010 authored *History of Stainless Steel*. He has authored several dozen articles, including “Development of the Unified Numbering System for Metals,” “The Naming and Numbering of Stainless Steels,” and “What’s in a Name?” He has worked at various times as an editorial consultant for ASM International, ASTM, the Association for Iron & Steel Technology, the Society of Automotive Engineers, and the Specialty Steel Industry of North America.

Cobb also is a guest editor for *Stainless Steel World*, a Dutch magazine, creating a monthly feature story under the byline “Cobb’s Corner.”

He holds a patent on a process for manufacturing fuel elements for nuclear submarines. He is a Life Member of ASM International, and a member of ASTM and Committee A-1 on Steel, Stainless Steel, and Related Alloys. Cobb and his wife reside in Kennett Square, Pennsylvania.
Introduction

Without doubt, none of the arts is older than agriculture, but that of the metals is not less ancient; in fact they are at least equal and coeval, for no mortal man ever tilled a field without implements. In truth, in all the works of agriculture, as in other arts, implements are used which are made of metals which could not be made without the usage of metals; for this reason the metals are of the greatest necessity to man . . . for nothing is made without tools.

—Vannoccio Biringuccio, Italy, 1540

Contents

The contents of the book fall into the following categories:

- Detailed descriptions of each of the 73 metallic elements, including the date of discovery, the discoverer, the meaning and source of the name, and principal applications.
- Tables in the Appendix showing the physical properties of each element and its abundance in the earth’s crust and in seawater.
- Descriptions of alloys and groups of alloys, often with sources for further information.
- Definitions of metallurgical terms, with references.
- Descriptions of test methods, with references to ASTM tests.
- Historical notes on the prominent men and women in the field of metallurgy.
- Descriptions and illustrations of notable metal structures and applications.
- A separate Metals History Timeline of metals, metallurgy, and notable events and people.

The Earliest Discoveries

The field of metals and metallurgy begins with the seven metals of antiquity, dating from the Bronze and Iron Ages: gold, silver, copper, iron, lead, tin, and mercury. They were found in ores, present primarily as oxides, sulfides, or silicates, and occasionally in pure form as nuggets. The metals were discovered by ancient man inadvertently roasting around a fire these mineral-laden rocks. This led to the building of furnaces to recover the metals, which were made into items such as ornaments, utensils, farming implements, knives, axes, spears, and swords.

In those early days, men associated metals with the gods and the planets. Brilliant, yellow gold became associated with the sun, silver with the moon, and
Mars, the god of war, was for the strong metal, iron. Dark lead was associated with the planet Saturn; the word *saturnine* means heavy, grave, gloomy, dull—the opposite of *mercurial*. Mercury, also known as quicksilver, fell, naturally, to Mercury, the planet that moved fastest across the sky.

**The Ages of Man**

In 1818, the Danish archeologist Christian Jürgensen Thomsen (1788–1865) divided the ages of man into the Stone, Bronze, and Iron Ages, illustrating the significance of these materials during certain periods of history. His work was not published until 1836 when it appeared in Copenhagen in *Ledetraad til Nordisk Oldkyndighed* (*Guideline to Scandinavian Antiquity*). He did not assign dates, but the dating of artifacts suggests the beginning of the Bronze Age from 3300 to 1200 B.C., depending upon the location. Iron implements found in the Indian subcontinent dating back to circa 1800 B.C. indicate the earliest beginning of the Iron Age in any region. (If Thomsen were alive today, he might well create a Steel Age that started in 1855 with Henry Bessemer’s great invention for mass production of steel from molten pig iron.)

A copper-arsenic bronze alloy may have been the first alloy discovered, because copper and arsenic often occurred in the same mineral. When copper was smelted, it also would be mixed with tin to form a preferred type of bronze. The bronze alloys were harder than copper and better suited for tools and weapons.

When iron ore was discovered, it was heated to a red heat with charcoal and the spongy mass, called a *bloom*, was squeezed and hammered to remove some of the silica slag. The 1–2% of slag remaining in the mass consisted of long thin strings that contributed to the properties of the metal that became known first as *iron*, and in the 18th century as *wrought iron*, apparently to ensure it was not confused with *cast iron*. The product also had approximately 0.02% C. This, then, was the *iron* of the Iron Age. There never was a pure form of iron, except what was produced in modern times for experimental purposes. But the iron worked just fine. It eventually would be the stuff of the Eiffel Tower. In addition to its strength and malleability, iron possesses good corrosion resistance.

Although the term *wrought iron* is still often used for some products made today, it is not the wrought iron of old; it is ordinary steel and will have no corrosion resistance. In 1969, the last wrought iron producer in the United States, the A.M. Byers Company of Pittsburgh, closed its doors. Their process was labor intensive and they could not compete with other metals.

With the discovery of all seven of the ancient metals likely having occurred no later than 1000 B.C., it is interesting to note that over 2000 years passed until the next metal was discovered. About 1250 A.D., a German monk by the name
Introduction

of Albertus Magnus discovered arsenic. About 1450, bismuth was recognized as a new metal by Basilius Valentinus of Erfut, Germany. He called it “wismut,” which the early mineralogists Latinized to “bismutum.” In De Re Metallica, published in 1556, Georgius Agricola mentioned that zinc was identified as a metal in India in the 13th century.

During the last half of the 18th century, a dozen metals were discovered that included, in chronological order, cobalt, nickel, manganese, molybdenum, tellurium, tungsten, uranium, zirconium, titanium, yttrium, beryllium, and chromium. It was many years before these metals were actually put to use.

The 19th century, with the Industrial Revolution in full swing, saw the discovery, in chronological order, of niobium, tantalum, iridium, palladium, rhodium, potassium, sodium, boron, barium, calcium, magnesium, strontium, cerium, lithium, cadmium, selenium, silicon, aluminum, thorium, vanadium, lanthanum, erbium, terbium, ruthenium, cesium, rubidium, thorium, indium, and gallium.

In the early part of the 20th century, the final eight metals were discovered (not counting the trans-uranium elements): europium, lutetium, hafnium, rhenium, technetium, promethium, francium, and astatine.

The Naming and Numbering of Metals

Each of the elements was called a different name in every language. Iron, for example, was ferrum in Latin, hierro in Spanish, fer in French, and eisen in German. But scientists in virtually every country have agreed on the same chemical symbol for each metal, with the exception of a disagreement over whether one element should be called columbium (Cb) or niobium (Nb). The naturally occurring metallic elements also have atomic numbers in accordance with the periodic table of elements, ranging from atomic number 3 for lithium to number 92 for uranium.

However, the identification system for alloys, which are mixtures of two or more chemical elements, one of which is a metal, has been far more complicated, so much so that it requires large reference books such as Stahlschlüssel (Key to Steel), published in Germany, just to list all of the steels with their names, numbers, and chemical compositions, for each of approximately 20 countries.

What Is a Metal?

There is no generally agreed-upon definition of metal, and there probably does not need to be. Several approaches to the subject are listed subsequently.
In *De Re Metallica*, published in 1556, German mineralogist Georgius Agricola wrote the following description, which was translated from Latin in 1912 by future U.S. president Herbert Clark Hoover and his wife, Lou Henry Hoover:

Metal body, by nature either liquid or somewhat hard. The latter may be melted by the heat of fire, but when it is cooled down again and lost all heat it becomes hard again and resumes its proper form. In this respect it differs from the stone which melts in the fire, for although the latter regains its hardness, yet loses its pristine form and properties. Traditionally there are six different kinds of metals, namely gold, silver, copper, iron, tin, and lead. There are really others, for quicksilver is a metal, although the Alchemists disagree with us on this subject, and bismuth is also. The ancient Greek writers seem to have been ignorant of bismuth [sic], wherefore Ammonius rightly states that there are many species of metal, animals, and plants that are unknown to us. Stibium when melted in the crucible and refined has as much right to be regarded as a proper metal as is accorded to lead by writers. If, when smelted, a certain amount be added to tin, a bookseller’s alloy is produced from which the type is made that is used by those who print books on paper. Each metal has its own form which it preserves when separated from those metals which were mixed with it. Therefore neither electrum nor stannum is a real metal, but rather an alloy of two metals. Electrum is an alloy of gold and silver, stannum of lead and silver. And yet if silver is to be taken from stannum, then lead remains and not stannum. Whether brass, however, is found as native metal or not, cannot be ascertained by any surety. We only know of the artificial brass, which consists of copper tinted with the color of the mineral calamine. And yet if any should be dug up, it would be a proper metal. Black and white copper seem to be different from the red kind. Metal, therefore, is by nature either solid, as I have stated, or fluid, as in the unique case of quicksilver. But enough now, concerning the simple kinds.

In 1965, British metallurgist Donald Birchon inserted the following statement in his *Dictionary of Metallurgy*:

Metal. There is no rigorous definition of a metal. Earlier attempts to define it in terms of ductility, lustre, conductivity, etc., all fail due to anomalies or inability to be exclusive, and the chemical definition of a substance whose hydroxide is alkaline fails since it does not define materials having commonly accepted “metallic” properties.

A more acceptable approach is a crystalline material, in which the ions are connected indirectly through the field of free electrons surrounding
them. Each ion attracts as many neighboring ions as it can, giving a close-packed structure of short bonds, therefore good strength and relatively high density, associated with good electrical and thermal conductivity, ductility, and reflectivity.

The Nature of Metals

Everything on earth is composed of one or more of the 92 natural elements that fall into two groups: metals and nonmetals. The nonmetals consist of the gases hydrogen, oxygen, and nitrogen plus the inert gases argon, krypton, xenon, and neon. The other nonmetallic elements are carbon, phosphorus, sulfur, chlorine, bromine, fluorine, radon, and iodine.

The 73 naturally occurring metals are derived primarily from minerals in the earth’s crust in the form of oxides, silicates, or sulfides. Iron, for example, is found as iron oxide in several different minerals. Iron is separated from the oxide by heating at a high temperature with coke, which provides carbon that combines with the oxygen of the ore to allow molten iron to be produced. Many of the smelting procedures are very complex.

Each metal is unique because its atoms are composed of a specific number of protons, neutrons, and electrons. This means that the properties of each metal are different. The density of each metal, for example, is different. Lead is approximately four times as heavy as aluminum. The melting points are different and vary from \(-38.89^\circ\text{C} (-38^\circ\text{F})\) for mercury to \(3410^\circ\text{C} (6170^\circ\text{F})\) for tungsten.

The thermal conductivities are mostly different, with copper and silver being almost twice as heat conductive as aluminum. The strengths of the metals vary considerably, and some metals are much stronger than others at elevated temperatures. Metals also have enormous differences with respect to their corrosion resistance in various environments.

The unique properties of each metal give rise to special uses. Copper wire, for example, is ideal for conducting electricity. Aluminum is the ideal metal for beverage cans, and lead is the best possible metal for storage batteries for cars. Tungsten and molybdenum are ideal for the fine filaments in incandescent bulbs. Pure chromium metal is as brittle as glass but is applicable for the very thin chrome plate finish on steel. Gold is the most highly prized metal for its appearance and the most precious to own.

The Development of Alloys

Alloys are mixtures of two or more chemical elements, one of which is a metal. For example, iron, a metal, combined with 1% or less of carbon, creates
alloys of steel. Each of the metals described previously can be combined to make dozens or hundreds of alloys. One of the most interesting things in the field of metallurgy is that iron and carbon can be mixed to form the greatest number of alloys of any metal. These are primarily steels and cast irons. Some of the steels are just iron and carbon alloys, but there are hundreds of other alloys that have been created by adding small or large amounts of chromium, molybdenum, vanadium, tungsten, and other elements. The total number of steels is approximately 5000. The so-called tool steels are used to forge, roll, press, and cut steels themselves and all the other metals and alloys, in addition to providing the tools and equipment necessary to produce almost everything.