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# 材料手册 2

常用的有色金属及其合金

François Cardarelli

# Materials Handbook

A Concise Desktop Reference

*Second Edition*



哈尔滨工业大学出版社  
HARBIN INSTITUTE OF TECHNOLOGY PRESS



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by François Cardarelli

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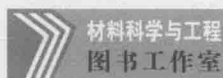
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François Cardarelli

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# Materials Handbook

**A Concise Desktop Reference**

2nd Edition



**Springer**

## Dedication for the First Edition

The *Materials Handbook: A Concise Desktop Reference* is dedicated to my father, Antonio, and my mother, Claudine, to my sister, Elsa, and to my spouse Louise Saint-Amour for their love and support. I want also to express my thanks to my two parents and my uncle Consalvo Cardarelli, which in close collaboration have provided valuable financial support when I was a teenager to contribute to my first fully equipped geological and chemical laboratory and to my personal comprehensive scientific library. This was the starting point of my strong and extensive interest in both science and technology, and excessive consumption of scientific and technical literature.

*François Cardarelli*

## Dedication for the Second Edition

The *Materials Handbook: A Concise Desktop Reference* is dedicated to my father, Antonio, and my mother, Claudine, to my sister, Elsa, and to my wife Elizabeth I.R. Cardarelli for their love and support. I want also to express my thanks to my two parents and my uncle Consalvo Cardarelli, which in close collaboration have provided valuable financial support when I was a teenager to contribute to my first fully equipped geological and chemical laboratory and to my personal comprehensive scientific library. This was the starting point of my strong and extensive interest in both science and technology, and excessive consumption of scientific and technical literature.

*François Cardarelli*

## Acknowledgements for the First Edition

Mr. Nicholas Pinfield (engineering editor, London), Mr. Jean-Étienne Mittelman (editor, Paris), Mrs. Alison Jackson (editorial assistant, London), and Mr. Nicolas Wilson (senior production controller, London) are gratefully acknowledged for their valued assistance, patience, and advice.

## Acknowledgements for the Second Edition

Mr. Anthony Doyle (senior engineering editor), Mr. Oliver Jackson (associate engineering editor), and Mr. Nicolas Wilson (editorial coordinator) are gratefully acknowledged for their valued assistance, patience, and advice.

## Units Policy

In this book the only units of measure used for describing physical quantities and properties of materials are those recommended by the *Système International d'Unités* (SI). For accurate conversion factors between these units and the other non-SI units (e.g., cgs, fps, Imperial, and US customary), please refer to the reference book by the same author:

Cardarelli, F. (2005) *Encyclopaedia of Scientific Units, Weights, and Measures. Their SI Equivalences and Origins*. Springer, London New York. ISBN 978-1-85233-682-1.

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- (2) research scientist at the Institute of Marine Biogeochemistry (CNRS & École Normale Supérieure, Paris, France) for the environmental monitoring of heavy-metal pollution by electroanalytical techniques;
- (3) research scientist for the preparation by electrochemistry in molten salts of tantalum protective thin coatings for the chemical-process industries (sponsored by Electricité de France);
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- (10) principal electrochemist at Materials and Electrochemical Research (MER) Corp., Tuscon (Arizona, USA) working on the electrowinning of titanium metal powder from composite anodes and other materials related projects.

# Introduction

Despite the wide availability of several comprehensive series in materials sciences and metallurgy, it is difficult to find grouped properties either on metals and alloys, traditional and advanced ceramics, refractories, polymers and elastomers, composites, minerals and rocks, soils, woods, cement, and building materials in a single-volume source book.

Actually, the purpose of this practical and concise reference book is to provide key scientific and technical materials properties and data to materials scientists, metallurgists, engineers, chemists, and physicists as well as to professors, technicians, and students working in a broad range of scientific and technical fields.

The classes of materials described in this handbook are as follows:

- (i) metals and their alloys;
- (ii) semiconductors;
- (iii) superconductors;
- (iv) magnetic materials;
- (v) dielectrics and insulators;
- (vi) miscellaneous electrical materials (e.g., resistors, thermocouples, and industrial electrode materials);
- (vii) ceramics, refractories, and glasses;
- (viii) polymers and elastomers;
- (ix) minerals, ores, and gemstones;
- (x) rocks and meteorites;
- (xi) soils and fertilizers;
- (xii) timbers and woods;
- (xiii) cement and concrete;
- (xiv) building materials;
- (xv) fuels, propellants, and explosives;

- (xvi) composites;
- (xvii) gases;
- (xviii) liquids.

Particular emphasis is placed on the properties of the most common industrial materials in each class. The physical and chemical properties usually listed for each material are as follows:

- (i) physical (e.g., density, viscosity, surface tension);
- (ii) mechanical (e.g., elastic moduli, Poisson's ratio, yield and tensile strength, hardness, fracture toughness);
- (iii) thermal (e.g., melting and boiling point, thermal conductivity, specific heat capacity, coefficients of thermal expansion, spectral emissivities);
- (iv) electrical (e.g., resistivity, relative permittivity, loss tangent factor);
- (v) magnetic (e.g., magnetization, permeability, retentivity, coercivity, Hall constant);
- (vi) optical (e.g., refractive indices, reflective index, dispersion, transmittance);
- (vii) electrochemical (e.g., Nernst standard electrode potential, Tafel slopes, specific capacity, overpotential);
- (viii) miscellaneous (e.g., relative abundances, electron work function, thermal neutron cross section, Richardson constant, activity, corrosion rate, flammability limits).

Finally, detailed appendices provide additional information (e.g., properties of the pure chemical elements, thermochemical data, crystallographic calculations, radioactivity calculations, prices of metals, industrial minerals and commodities), and an extensive bibliography completes this comprehensive guide. The comprehensive index and handy format of the book enable the reader to locate and extract the relevant information quickly and easily. Charts and tables are all referenced, and tabs are used to denote the different sections of the book. It must be emphasized that the information presented here is taken from several scientific and technical sources and has been meticulously checked and every care has been taken to select the most reliable data.

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# 2

## Ferrous Metals and Their Alloys

The ferrous metals are defined as the three upper transition metals of group VIII B (8, 9, and 10) of Mendeleev's periodic chart, that is, iron (Fe), cobalt (Co), and nickel (Ni), along with chromium (Cr) and manganese (Mn), despite the fact that these two metals belong to groups VI B (6) and VII B (7), respectively. Manganese is included in this chapter because it has an important role in iron- and steel-making, while chromium, owing to its refractory behavior, will be described in the chapter on refractory metals (see Section 4.3.8). The selected physical and chemical properties of these five elements are listed in Table 2.1.

### 2.1 Iron and Steels

#### 2.1.1 Description and General Properties

Iron [7439-89-6], chemical symbol Fe, atomic number 26, and relative atomic mass 55.845(2), is the first element of the upper transition metals of group VIII B (8) of Mendeleev's periodic chart. The word iron comes from the Anglo-Saxon *iren*, while the symbol Fe and words such as ferrous and ferric derive from the Latin name of iron, *ferrum*. Pure iron is a soft, dense ( $7874 \text{ kg}\cdot\text{m}^{-3}$ ), silvery-lustrous, magnetic metal with a high melting point ( $1535^\circ\text{C}$ ). In addition, when highly pure iron has both a good thermal conductivity ( $80.2 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ ) and a low coefficient of linear thermal expansion ( $11.8 \mu\text{m}/\text{m}\cdot\text{K}$ ), it is a satisfactory electric conductor ( $9.71 \mu\Omega\cdot\text{cm}$ ).

Table 2.1. Selected properties of iron, cobalt, nickel, chromium, and manganese

Properties at 298.15 K (unless otherwise specified)	Iron (Ferrum)	Cobalt	Nickel	Chromium	Manganese	
Designations	Fe	Co	Ni	Cr	Mn	
Natural occurrence and economics	Chemical symbol (IUPAC) Chemical abstract registry umber [CARN] Unified numbering system [UNS] Earth's crust abundance ( $\text{mg}\cdot\text{kg}^{-1}$ ) Seawater abundance ( $\text{mg}\cdot\text{kg}^{-1}$ ) World estimated reserves ( $R/\text{tonnes}$ ) World annual production of metal in 2004 ( $P/\text{tonnes}$ ) Price of pure metal in 2004 ( $C/\text{\$US}\cdot\text{kg}^{-1}$ ) (purity in wt.%) Atomic number ( $Z$ )	[7439-89-6] [R30001] 25 $0.2 \times 10^{-4}$ n.a. 35,000 55-57 (99.8)	[7440-02-0] [N02200] 84 $5.6 \times 10^{-4}$ $70 \times 10^6$ $1.033 \times 10^6$ 12.85-13.35 (99.8)	[7440-47-3] [R20001] 102 $3 \times 10^{-4}$ $1 \times 10^6$ 30,000 10.25-10.65 (99.4)	[7439-96-5] [M20001] 950 $2 \times 10^{-4}$ $700 \times 10^6$ 100,000 1.3-1.4 (99.7)	
Atomic properties	Relative atomic mass $A_r$ ( $^{\circ}\text{C} = 12.000$ ) <sup>1</sup> Electronic configuration (ground state) Fundamental ground state Atomic or Goldschmidt radius ( $f/\text{pm}$ ) Covalent radius ( $f/\text{pm}$ ) Electron affinity ( $E_a/\text{eV}$ ) First ionization energy ( $E_i/\text{eV}$ ) Second ionization energy ( $\text{eV}$ ) Third ionization energy ( $\text{eV}$ ) Electronegativity $\chi_e$ (Pauling) Electronegativity $\chi_e$ (Allred and Rochow) Electron work function ( $W_e/\text{eV}$ ) X-ray absorption coefficient $\text{CuK}_{\alpha 1}$ ( $(\mu/\rho)/\text{cm}^2\cdot\text{g}^{-1}$ ) Thermal neutron cross section ( $\sigma_n/10^{-28}\text{m}^2$ ) Isotopic mass range Isotopes (including natural and isomers)	55.845(2) $[\text{Ar}]3d^64s^2$ $^7D_4$ 126 116 0.151 7.9024 16.1878 30.652 1.83 1.64 4.06 308 2.56 49-63 16	58.933200(9) $[\text{Ar}]3d^74s^2$ $^7F_{4/2}$ 125 116 0.662 7.8810 17.083 33.50 1.88 1.75 4.30 313 37.2 35-64 17	58.6934(2) $[\text{Ar}]3d^84s^1$ $^3F_4$ 125 115 1.160 7.6398 18.16884 35.19 1.91 1.75 4.40 45.7 37.2 53-67 14	51.9961(6) $[\text{Ar}]3d^54s^2$ $^6S_{5/2}$ 129 118 0.666 6.76664 16.4857 30.96 1.66 1.56 3.72 260 3.1 45-57 13	7.43402 15.63999 33.668 1.55 1.60 3.72 285 13.3 49-62 15
Nuclear properties						

Crystal structure (phase $\alpha$ )	bcc	hcp	fcc	bcc	Complex bcc
<i>Strukturbericht</i> designation	A2(W)	A3(Mg)	A1(Cu)	A2(W)	A12( $\alpha$ -Mn)
Space group (Hermann-Mauguin)	<i>Im</i> 3m	$P6_3/mmc$	<i>Fm</i> 3m	<i>Im</i> 3m	<i>I4</i> 3m
Pearson's notation	cI2	hP2	cF4	cI2	cI58
Crystal lattice parameters ( <i>a</i> , <i>b</i> , <i>c</i> ) [293.15 K]	<i>a</i> = 286.65	<i>a</i> = 250.71 <i>c</i> = 406.94	<i>a</i> = 352.38	<i>a</i> = 288.46	<i>a</i> = 891.39
Latent molar enthalpy transition ( $L_i/kJ.mol^{-1}$ )	5.11	0.25	2.98	0.0008	2.22
Phase transition temperature $\alpha$ - $\beta$ ( $T/K$ )	914	690 ( $\epsilon$ - $\alpha$ )	631.15	311.5	983.15
Density ( $\rho/kg.m^{-3}$ ) [293.15 K]	7874	8900	8902	7190	7440
Young's or elastic modulus ( <i>E</i> /GPa) (polycrystalline)	208.2	211	199.5	279	191
Coulomb's or shear modulus ( <i>G</i> /GPa) (polycrystalline)	81.6	82	76	115.3	79.5
Bulk or compression modulus ( <i>K</i> /GPa) (polycrystalline)	169.8	181.5	177.3	160.2	139.67
Mohs hardness (H/M)	4.0	5.5	4.5	8.5	5.0
Brinell hardness (H/B)	50-90 (460-520)	81-250	85-109	125	392-411
Vickers hardness (H/V) (hardened)	160 (608)	310 (1043)	172-184 (640)	1060 (1875-2000)	981
Yield strength proof 0.2% ( $\sigma_{0.2}$ /MPa)	131	758	148	362	241
Ultimate tensile strength ( $\sigma_{\text{tens}}$ /MPa)	689	800-875	462	415	496
Elongation ( <i>Z</i> /%)		15-30	48	44	40
Charpy impact value			230	160	
Creep strength (/MPa) (hardened)					
Longitudinal velocity of sound ( $V_L/m.s^{-1}$ )	5920	5730	5810	6850	5560
Transversal velocity of sound ( $V_T/m.s^{-1}$ )	3220	3000	3080	3980	3280
Static friction coefficient (vs. air)	1.0	0.30	0.70	0.46	0.69
Poisson ratio $\nu$ (dimensionless)	0.290	0.320	0.312	0.210	0.240

Crystallographic properties

Mechanical properties (annealed)