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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

哈爾濱工業大學出版社
HARBIN INSTITUTE OF TECHNOLOGY PRESS

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《材料手册》(8册)是 Springer ***Materials Handbook*** *A Concise Desktop Reference* (2nd Edition)的影印版。为使用方便，由原版1卷分为8册：

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本手册提供各种材料的物理和化学性质，是一本简洁的手边工具书。第二版与第一版的差别是扩充了新的家用材料，但重点是每一类常见的工业材料。

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François Cardarelli

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

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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.

Author Biography

Dr. François Cardarelli (Ph.D.)
Born in Paris (France) February 17, 1966
Canadian citizen

Academic Background

- Ph.D., chemical engineering (Université Paul Sabatier, Toulouse, France, 1996)
- Postgraduate degree (DEA) in electrochemistry (Université Pierre et Marie Curie, Paris, 1992)
- M.Sc. (Maîtrise), physical chemistry (Université Pierre et Marie Curie, Paris, 1991)
- B.Sc. (Licence), physical chemistry (Université Pierre et Marie Curie, Paris, 1990)
- DEST credits in nuclear sciences and technologies (Conservatoire National des Arts et Métiers, Paris, 1988)

- Associate degree (DEUG B) in geophysics and geology (Université Pierre et Marie Curie, Paris, 1987)
- Baccalaureate C (mathematics, physics, and chemistry) (CNED, Versailles, France, 1985)

Fields of Professional Activity

The author has worked in the following areas (in chronological order) since 1990.

(1) Research scientist at the Laboratory of Electrochemistry (Université Pierre & Marie Curie, Paris, France) for the development of a nuclear detector device for electrochemical experiments involving radiolabeled compounds;

(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);

(4) research scientist for the preparation and characterization of iridium-based industrial electrodes for oxygen evolution in acidic media at the Laboratory of Electrochemical Engineering (Université Paul Sabatier, Toulouse, France);

(5) registered consultant in chemical and electrochemical engineering (Toulouse, France);

(6) battery product leader in the technology department of ARGOTECH Productions, Boucherville (Québec), Canada, in charge of electric-vehicle, stationary, and oil-drilling applications of lithium polymer batteries;

(7) materials expert and industrial electrochemist in the lithium department of ARGOTECH Productions, involved in both the metallurgy and processing of lithium metal anodes and the recycling of spent lithium polymer batteries;

(8) materials expert and industrial electrochemist in the technology department of AVESTOR, Boucherville (Quebec), Canada, in charge of all strategic raw materials entering into the fabrication of lithium polymer batteries, as well as being in charge of the recycling process of spent lithium batteries;

(9) principal chemist, materials, in the technology department of RIO TINTO Iron and Titanium, Sorel–Tracy (Québec), Canada working on the electrowinning of titanium metal from titania-rich slags and on other novel electrochemical processes;

(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.

Contents

2 Ferrous Metals and Their Alloys

The ferrous metals are defined as the three upper transition metals of group VIIIB (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 VIB(6) and VIIB(7), respectively. Manganese is included in this chapter because it has an important role in iron- and steelmaking, 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 VIIIB(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 $kg.m^{-3}$), silvery-lustrous, magnetic metal with a high melting point (1535°C). In addition, when highly pure iron has both a good thermal conductivity (80.2 $W.m^{-1}.K^{-1}$) and a low coefficient of linear thermal expansion (11.8 μm/m.K), it is a satisfactory electric conductor (9.71 μΩ.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
Desig-nations	Chemical symbol (IUPAC)	Fe	Co	Ni	Cr	Mn
	Chemical abstract registry umber [CARN]	[7439-89-6]	[7440-48-4]	[7440-02-0]	[7440-47-3]	[7439-96-5]
	Unified numbering system [UNS]	[F00001]	[R30001]	[N02200]	[R20001]	[M20001]
Natural occurrence and economics	Earth's crust abundance (/mg.kg^{-1})	56300	25	84	102	950
	Seawater abundance (/mg.kg^{-1})	20×10^{-4}	0.2×10^{-4}	5.6×10^{-4}	3×10^{-4}	2×10^{-4}
	World estimated reserves (*R*/tonnes)	110×10^{9}	n.a.	70×10^{6}	1×10^{9}	700×10^{6}
	World annual production of metal in 2004 (*P*/tonnes)	940×10^{6}	35,000	1.033×10^{6}	30,000	100,000
	Price of pure metal in 2004 (*C*/$US.kg^{-1}) (purity in wt.%)	0.350 (98)	55–57 (99.8)	12.85–13.35 (99.8)	10.25–10.65 (99.4)	1.3–1.4 (99.7)
Atomic properties	Atomic number (Z)	26	27	28	24	25
	Relative atomic mass A_r ($^{12}C = 12.000$)[1]	55.845(2)	58.933200(9)	58.6934(2)	51.9961(6)	54.938049(9)
	Electronic configuration (ground state)	[Ar]$3d^6 4s^2$	[Ar]$3d^7 4s^2$	[Ar]$3d^8 4s^2$	[Ar]$3d^5 4s^1$	[Ar]$3d^5 4s^2$
	Fundamental ground state	$^5D_4$	$^4F_{9/2}$	$^3F_4$	$^7S_3$	$^6S_{5/2}$
	Atomic or Goldschmidt radius (/pm)	126	125	125	129	137
	Covalent radius (/pm)	116	116	115	118	118
	Electron affinity (E_A/eV)	0.151	0.662	1.160	0.666	n.a.
	First ionization energy (E_I/eV)	7.9024	7.8810	7.6398	6.76664	7.43402
	Second ionization energy (eV)	16.1878	17.083	18.16884	16.4857	15.63999
	Third ionization energy (eV)	30.652	33.50	35.19	30.96	33.668
	Electronegativity χ_a (Pauling)	1.83	1.88	1.91	1.66	1.55
	Electronegativity χ_a (Allred and Rochow)	1.64	1.75	1.75	1.56	1.60
	Electron work function (W_S/eV)	4.06	4.30	4.40	3.72	3.72
	X-ray absorption coefficient $CuK_{\alpha 1,2}$ ((μ/ρ) /cm^2.g^{-1})	308	313	45.7	260	285
Nuclear properties	Thermal neutron cross section ($\sigma_n/10^{-28}m^2$)	2.56	37.2	37.2	3.1	13.3
	Isotopic mass range	49–63	35–64	53–67	45–57	49–62
	Isotopes (including natural and isomers)	16	17	14	13	15

Crystallographic properties	Crystal structure (phase α)	bcc	hcp	fcc	bcc	Complex bcc
	Strukturbericht designation	A2(W)	A3(Mg)	A1(Cu)	A2(W)	A12(α-Mn)
	Space group (Hermann–Mauguin)	*Im3m*	$P6_3/mmc$	*Fm3m*	*Im3m*	*I43m*
	Pearson's notation	cI2	hP2	cF4	cI2	cI58
	Crystal lattice parameters (/pm) [293.15 K]	*a* = 286.65	*a* = 250.71 *c* = 406.94	*a* = 352.38	*a* = 288.46	*a* = 891.39
	Latent molar enthalpy transition (L_t/kJ.mol^{-1})	5.11	0.25	2.98	0.0008	2.22
	Phase transition temperature α–β (*T*/ K)	914	690 (ε–α)	631.15	311.5	983.15
Mechanical properties (annealed)	Density (*ρ*/kg.m^{-3}) [293.15 K]	7874	8900	8902	7190	7440
	Young's or elastic modulus (*E*/GPa) (polycrystalline)	208.2	211	199.5	279	191
	Coulomb's or shear modulus (*G*/GPa) (polycrystalline)	81.6	82	76	115.3	79.5
	Bulk or compression modulus (*K*/GPa) (polycrystalline)	169.8	181.5	177.3	160.2	139.67
	Mohs hardness (/HM)	4.0	5.5	4.5	8.5	5.0
	Brinell hardness (/HB)	50–90 (460–520)	81–250	85–109	125	392–411
	Vickers hardness (/HV) (hardened)	160 (608)	310 (1043)	172–184 (640)	1060 (1875–2000)	981
	Yield strength proof 0.2% (σ_{YS}/MPa)	131	758	148	362	241
	Ultimate tensile strength (σ_{UTS}/MPa)	689	800–875	462	415	496
	Elongation (Z/%)		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 ν (dimensionless)	0.290	0.320	0.312	0.210	0.240