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材料手册 1

材料的性能

François Cardarelli

Materials Handbook

A Concise Desktop Reference

Second Edition

哈爾濱工業大學出版社
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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

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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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

1 Properties of Materials

This section presents the most important mechanical, thermal, and optical quantities used to describe and characterize the properties of various classes of solid materials discussed in various sections of this book, while electrical and magnetic properties are described in the sections dealing with semiconductors, dielectrics, and magnetic materials. Finally, the properties of gases and liquids are described in their respective sections. For each physical quantity, the definition, physical equation, and SI unit are provided along with some orders of magnitude and range. The most common conversion factors encountered in metallurgy and materials science are listed in Table 1.14 at the end of this chapter.

1.1 Physical Properties

1.1.1 Mass Density

The ***mass density***, or simply ***density***, of a material is an intensive[1] physical quantity denoted by the Greek letter ρ (or d), which corresponds to the mass of the material, m, expressed in kg, divided by the total volume of the material, V, expressed in m^3. Hence, it has the dimension $[ML^{-3}]$ and is then expressed in the SI in $kg.m^{-3}$:

$$\rho = m/V.$$

[1] An intensive quantity does not vary with dimensions of the system (e.g., mass, volume).

The temperature dependence of the density is given in a first approximation by the following linear relationships:

$$\rho(T) = \rho_0/[1 + \beta(T - T_0)] = \rho_0 \cdot [1 - \beta(T - T_0)] = (\rho_0 + \rho_0\beta T_0) - \rho_0\beta T = A - BT,$$

where T is the absolute thermodynamic temperature in K and β the cubic thermal expansion coefficient in K^{-1}.

1.1.2 Theoretical Density or X-ray Density of Solids

The mass density ρ of crystallized solids expressed in $kg.m^{-3}$ can be calculated quite accurately from both the number of atoms or molecules per formula unit and the crystal lattice parameters obtained by x-ray diffraction. For that reason, it is sometimes called the ***x-ray density*** , or simply the ***theoretical density***, of the crystal. It can be calculated using the following equation:

$$\rho_{xray} = ZM/N_A V_{cell},$$

with

Z the dimensionless number of atoms or molecules per formula unit (apfu),
M the molar atomic or molecular mass in $kg.mol^{-1}$,
N_A Avogadro's constant, $6.02204531 \times 10^{23}$ mol^{-1}, and
V_{cell} the volume of the unit cell based on crystal lattice parameters in m^3.

1.1.3 Apparent, Bulk, and Tap Densities

The ***apparent density***, also called the ***true density***, ***real density***, or ***absolute density***, ρ_{app}, expressed in $kg.m^{-3}$, is obtained when the volume measured excludes the pores as well as the void spaces between particles within the bulk sample. Absolute density is determined by pycnometry using water or another liquid that is expected to fill the pores in the sample, thus removing their volume from the measurement. Sometimes the material is subjected to boiling in the same liquid to ensure pore penetration, and sometimes the sample is evacuated prior to immersion to assist pore filling. However, surface-tension effects and entrapped gases resist the filling of very small pores. Therefore the best method consists in determining the apparent density by helium pycnometry:

$$\rho_{bulk} = m_{particles}/V_{particles}.$$

The ***bulk density***, ρ_{bulk}, expressed in $kg.m^{-3}$, is used for characterizing solids in powder form and particulates and corresponds to the mass of a solid in powder form divided by the overall volume of the solids including voids containing air trapped between particles:

$$\rho_{bulk} = m_{particles}/(V_{particles} + V_{voids}).$$

The ***tap density***, ρ_{tap}, expressed in $kg.m^{-3}$, corresponds to the apparent density of a powder obtained from filling a container with the sample material and vibrating or tapping it under specified conditions (e.g., ASTM standard test methods B527, D1464, and D4781) to obtain near-optimum packing.

1.1.4 Specific Weight

The ***specific weight*** of a material, denoted by the Greek letter γ, corresponds to the weight of material per unit volume. Its dimensions are $[ML^{-2}T^{-2}]$, and it is expressed in $N.m^{-3}$:

$$\gamma = mg_n/V = \rho g_n.$$

1.1.5 Specific Gravity

The ***specific gravity***, denoted *d*, *S.G.*, or simply *G*, is a dimensionless physical quantity equal to the ratio of the mass density of the material at a given temperature (t_1) to the mass density of a reference fluid selected as a standard at a given temperature (t_2). Since the mass density of materials varies with temperature, for a precise definition the temperature of both materials must be stated:

$$d = \rho_{material}(t_1)/\rho_{ref}(t_2) = \text{S.G.}$$

Usually, the specific gravity of liquids and solids refers to the maximum mass density of pure water (i.e., 999.973 $kg.m^{-3}$ measured at 3.98°C or sometimes 999.972 $kg.m^{-3}$ measured at 4°C), but other solvents could also be used as standards. For instance, common specific gravities commonly used in the industry are $d^{20°}_{4°}$, $d^{20°}_{15°}$, and $G^{60°F}_{60°F}$.

While the specific gravity of gases refers to the mass density of dry air measured for normal conditions of temperature and pressure (NTP; i.e., 273.15K and 101.325 kPa), for ideal gases, the specific gravity relative to air at the same temperature and pressure can be written as the ratio of their relative molar masses:

$$d_{gas} = \rho_{gas}(P, T)/\rho_{air}(P, T) = M_{gas}/M_{air}.$$

Therefore, under normal temperature and pressure, the specific gravity of a gas is given approximately by the following practical relation:

$$d_{gas} \sim M_{gas}/28.964.$$

1.1.6 Buoyancy and Archimedes' Principle

The Archimedes theorem explains that all bodies immersed in an ideal fluid encounter a vertical thrust force oriented toward the top, called the buoyancy force, and equal as absolute value to the weight of the volume of the fluid displaced. This force is called the buoyancy force, denoted **b** and expressed in newtons (N). Actually, for a solid material, S, having a volume V_S in m^3 immersed in a fluid (i.e., gas or liquid), F, with a mass density, ρ_F in $kg.m^{-3}$, the buoyancy force acting on the solid body can be written as follows:

$$\mathbf{b} = -\rho_F V_S \mathbf{g}_n.$$

It is then possible to express the apparent weight of a solid material immersed in a fluid:

$$\mathbf{P}_{apparent} = \mathbf{P}_{actual} + \mathbf{b},$$

$$\mathbf{P}_{apparent} = m_S \mathbf{g}_n - \rho_F V_S \mathbf{g}_n,$$