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材料手册 5

陶瓷 耐火材料 玻璃 聚合物 弹性体

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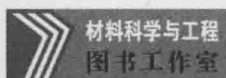
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本手册提供各种材料的物理和化学性质,是一本简洁的手边工具书。第二版与第一版的差别是扩充了新的家用材料,但重点是每一类常见的工业材料。

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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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Mr. Nicholas Pinfield (engineering editor, London), Mr. Jean-Étienne Mittelmann (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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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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10

Ceramics, Refractories, and Glasses

10.1 Introduction and Definitions

The word “ceramics” is derived from the Greek *keramos*, meaning solid materials obtained from the firing of clays. According to a broader modern definition, ceramics are either crystalline or amorphous solid materials involving only ionic, covalent, or iono-covalent chemical bonds between metallic and nonmetallic elements. Well-known examples are silica and silicates, alumina, magnesia, calcia, titania, and zirconia. Despite the fact that, historically, oxides and silicates have been of prominent importance among ceramic materials, modern ceramics also include borides, carbides, silicides, nitrides, phosphides, and sulfides.

Several processes, namely calcining and firing, are extensively used in the manufacture of raw and ceramic materials, and they must be clearly defined. Calcining consists in the heat treatment of a raw material prior to being used in the final ceramic material. The purpose of calcination is to remove volatile chemically combined constituents and to produce volume changes. Firing or burning is the final heat treatment performed in a kiln to which a green ceramic material is subjected for the purpose of developing a strong chemical bond and producing other required physical and chemical properties.

As a general rule ceramic materials can be grouped into three main groups: traditional ceramics, refractories and castables, and advanced or engineered ceramics.

Before describing each class, a description of the most common raw materials used in the manufacture of traditional and advanced ceramics, refractories, and glasses is presented below.

10.2 Raw Materials for Ceramics, Refractories and Glasses

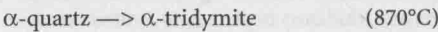
10.2.1 Silica

Silica, with the chemical formula SiO_2 and relative molar mass of 60.084, exhibits a complex polymorphism characterized by a large number of reversible and irreversible phase transformations (Figure 10.1) usually associated with important relative volume changes ($\Delta V/V$). At low temperature and pressure *beta-quartz* (β -quartz) [14808-60-7] predominates, but above 573°C, it transforms reversibly into the high-temperature *alpha-quartz* (α -quartz) [14808-60-7] with a small volume change (0.8 to 1.3 vol.%):



Quartz exhibits a very low coefficient of thermal expansion ($0.5 \mu\text{m/m.K}$) and an elevated Mohs hardness of seven. Large and pure single crystals of quartz of gem quality called *lascas* are used due to their high purity in the preparation of elemental silicon for semiconductors (see Section 5.8.1).

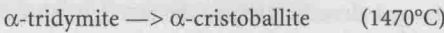
At a temperature of 870°C, α -quartz transforms irreversibly into *alpha-tridymite* (α -tridymite, orthorhombic) [15468-32-3] with an important volume change of 14.4 vol.% as follows:



But in practice, the kinetic of the above reaction is too slow, and tridymite never forms below 1250°C, and hence at 1250°C or 1050°C in the presence of impurities, α -quartz transforms irreversibly into *alpha-cristoballite* (α -cristoballite, tetragonal) [14464-46-1] with an important volume change (17.4 vol.%) as follows:



However, if the temperature is raised to 1470°C, α -tridymite transforms also irreversibly into *alpha-cristoballite* (α -cristoballite) without any change in volume as follows:



On cooling α -cristoballite transforms reversibly into *beta-cristoballite* (β -cristoballite, cubic) at 260°C with a volume change 0.2 to 2.8 vol.%:



Finally, α -cristoballite melts at 1713°C while α -tridymite melts at 1670°C. Upon cooling silica melt yields amorphous *fused silica* [60676-86-0].

There also exist two high-pressure polymorphs of silica called *coesite* and *stishovite* (see Section 12.7) that occur in strongly mechanically deformed metamorphic rocks (e.g., impactites), but these two phases are usually not encountered in ceramics, refractories, and glasses.

Industrially, silica products are classified into two main groups: *natural silica* products—quartzite, silica sand, and diatomite—and *specialty silicas* including fumed silica, silica gel, microsilica, precipitated silica, fused silica, and vitreous silica.

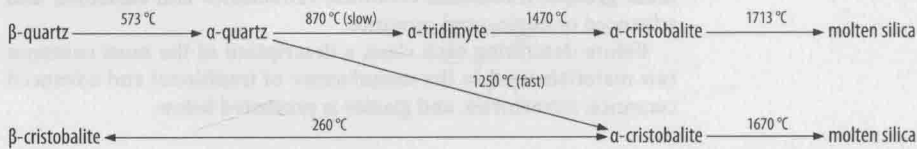


Figure 10.1. Polymorphs of silica (SiO_2)