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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

Engineering Materials Textbook Series

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by François Cardarelli

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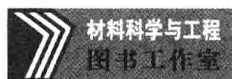
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 **Springer**

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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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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14

Soils and Fertilizers

14.1 Introduction

The science of soils, also called *pedology*, considers the soil as a complex ecological entity and not only as an inert geological material resulting simply from the weathering and alteration of the underlying bedrock. Actually, soil is a complex and evolutive system that originates from the interaction between the bedrock with other important factors such as the climate, the vegetation and the animal activity. During its evolution, called *pedogenesis*, the soil first forms a primitive and superficial thin layer of organic matter mixed with altered rock, later the incorporation of organic matter together with the lixiviation of some inorganic material yields to a thicker strata split into different zones with distinct texture, structure and color called *horizons*, all the horizons constituting the overall *profile* of the soil.

According to Duchaufour, three major horizons develop during the evolution of a soil. First, primitive soils consist essentially of an organic layer made of vegetable debris called horizon O (or A_0) and an underlying layer of altered rock called horizon C. As time passes, the intimate mixing of previous materials gives rise to the superficial horizon A. This dual AC profile is characteristic of poorly evolved soils or young soils. Later the weathering of minerals from rock debris leads to the formation of an intermediate horizon denoted (B). Afterwards, the mass transfer from horizon A brings additional matter to (B) transforming it into an illuvial horizon B. The time sequence of the profiles: AC \rightarrow A(B)C \rightarrow ABC is the common evolution process of a soil.

14.2 History

The first soil classification was established in China during the Vao dynasty (2357–2261 BC) more than four thousand years ago. At that time, soils were grouped into nine classes, based on their productivity. In ancient times, soil was only considered as a medium for plant growth. Later, in the Middle Ages, it was well known that manure applied to soils improved crop growth. For instance, Plaggen cultivation was practiced for a long time in Europe, leaving Plaggen soils. Plaggen cultivation involved stripping the topsoil of grassland for use as litter in stables. After becoming mixed with manure, the material was applied to arable land to improve crop production. From the 1660s onwards, various members of *The Royal Society of London* proposed various soils classification that incorporated elements of a natural or scientific approach in their criteria such as Boyle (1665) and Lister (1684). In 1840, the German chemist Justus von Liebig initiated a revolution in soil science and agriculture. He proved that plants assimilate mineral nutrients from the soil and proposed the use of mineral fertilizers to fortify deficient soils. Crop production was increased tremendously using mineral fertilizers. Another effect was the shift from extensive to intensive techniques in agriculture, which influenced soils. In 1853, Thaer published a classification that combined texture as a primary subdivision with further subdivisions based on agricultural suitability and productivity. Several classifications based largely on geologic origin of soil material were also proposed in the 19th century by Fallou (1862), Peters (1885) and Richtofen (1886). From this period on, the disciplines of agricultural chemistry, geography, and geology provided a broad but somewhat fragmented background from which pedology emerged as a separate discipline in the late 19th century more or less independently in Russia by Dokuchaev and coworkers and in the United States by Hilgard and coworkers. In 1883, Dokuchaev carried out a comprehensive field study in Russia, where he described the occurrence of different soils thoroughly using soil morphologic features. Due to his observations in the field he hypothesized that different environmental conditions result in the development of different soils. He defined soil as an independent natural evolutionary body formed under the influence of five factors, of which he considered vegetation and climate the most important. Dokuchaev is generally credited with formalizing the concept of the five soil forming factors, which provides a scheme for study of soils as natural phenomena. The soil classification developed by Dokuchaev and his colleagues Glinka and Neustruyev was based the genetic aspect of the soil formation. In the United States, Hilgard (1892) emphasized the relationship between soils and climate, which is known as the climatic zone concept. In 1912, Coffey produced the first soil classification system for the United States based on the soil genesis principles of Dokuchaev and Glinka. In 1951, Marbut introduced the concepts of Coffey into soil survey programs in the U.S. carried out by the *United States Department of Agriculture* (USDA). Between 1912 and the 1960 the soil classification in the United States used a genetic approach. In 1941, Jenny put together a detailed description of the five soil forming factors responsible for the development of different soils. In 1959, Simonson stressed that many genetic processes are simultaneously and/or sequentially active in any soil. Hence, a soil classification based on principles of soil genesis would not be favorable. In 1967, Duchaufour and co-workers of the CPCS established the *Classification Française des Sols*. Later in 1973, the *Food and Agriculture Organization* (FAO) introduced a simplified version of the USDA classification for the mapping of the soils worldwide. This classification is easier to understand because it uses a nomenclature with a terminology common in pedology and was extensively used by soil scientists in underdeveloped countries.

14.3 Pedogenesis

The three major processes are involved during pedogenesis:

- (i) the weathering and alteration of minerals from the bedrock with clays formation;
- (ii) the incorporation of organic matter from superficial horizons;
- (iii) the mass transfer between horizons.

14.3.1 Weathering and Alteration of Minerals and Clays Formation

The mineral fraction in soils comes essentially from:

- (i) physical degradation, called **erosion**; and
- (ii) chemical transformation, called **weathering** or **alteration**, of the underlying bedrock.

These two distinct processes lead to the formation of secondary minerals mainly phyllosilicates such as clays, of soluble products (e.g., carbonates or silica) lixiviated by percolating waters and of colloids usually iron and aluminum sesquioxides complexed by humic acids. While physical degradation involves mechanical (e.g., abrasion, impact) or thermal (e.g., thermal shock) processes, alteration involves only chemical reactions such as hydrolysis influenced by pH conditions and/or the oxidation of primary materials depending on the Eh (redox potential) conditions. Whatever the type of underlying rock, the end product is always a clay except when silica is totally absent from the bedrock, the composition of the clay depending on the type of climate and the time over which the evolution process takes place. These conditions are summarized in Table 14.1.

Table 14.1. Clay minerals in soils vs. initial conditions

Bedrock	Confined slightly acid	Lixiviated acidic
Alkaline rocks (e.g., limestone, basalt)	Montmorillonite	Illite
Acidic rock (e.g., granite, sandstone)	Kaolinite	

14.3.2 Incorporation of Organic Matter

The topsoil, with undecomposed or partially decomposed litter such as leaves, twigs, moss, and lichens, represents the major source of organic matter in soils. During its decomposition by normal biological activity, two major processes are involved:

- (i) **mineralization** that produces soluble inorganic anions (e.g., NO_3^- , CO_3^{2-} , SO_4^{2-}) or gaseous molecules (e.g., NH_3 , CO_2 , CH_4);
- (ii) **humification** or the formation of complexes by the minerals in clays with humic acids released by the biochemical degradation of cellulose and lignin. These stable argillohumic complexes that resist further biological degradation, are the main components of **humus** named from the Latin word for soil. The evolution of the humus strongly depends on the oxygenation conditions (i.e., aerobic or anaerobic regimes) and roughly three types of humus can be distinguished (see Table 14.2).

Table 14.2. Different types of humus

Designation	Conditions	Description
Mor	Formed onto siliceous bedrocks with low pH and with coniferous or resinous cover (e.g., podzols)	Raw humus with a fibrous or lamellar structure.
Moder	Formed under anaerobic and poorly drained conditions (e.g., hydromorphic soils) where the accumulation of undecomposed litter (e.g., moss, sphagnum) is important like in marsh, swamp, and peat ¹ bogs.	Undecomposed litter and moss, sphagnum.
Mull	Formed under aerobic conditions and pH close to neutrality where biological processes are highly active.	Exhibits a dark-brown color and a grumelous texture due to argillo-humic complexes.

14.3.3 Mass Transfer between Horizons

In soils, several processes insure the mass transfer between the upper and lower horizons. Due to the action of gravity, major processes are of the descending type but some ascending processes also occur.

14.3.3.1 Descending Processes

Three descending processes ensure the mass transfer in soils; these process are:

- (i) lixiviation;
- (ii) cheluviation;
- (iii) lessivage.

Lixiviation. Lixiviation involves the removal of soluble alkali- and alkaline-earth-metal cations (e.g., Na⁺, K⁺, Ca²⁺, and Mg²⁺) by infiltrating water charged with anions. The anions involved are either nitrates, carbonates, sulfates or humates. Lixiviation strongly depends on the pH and oxydo-reduction conditions existing in the soil. Heavy metal cations such as Fe²⁺, Mn²⁺, or Al³⁺ are usually complexed by humic acids and they are hence not lixiviated except under highly acidic or reducing conditions. Soils developed on calcareous or dolomious bedrocks undergo a particular type of lixiviation called decarbonatation involving dissolved carbon dioxide. As a general rule, the lixiviation process affects the entire soil profile without the concentration of lixiviate into lower horizons.

Cheluviation. Cheluviation involves the transport of organo-metallic complexes (i.e., chelates) of iron and aluminum. Once transported to the lower horizon B, the iron and aluminum precipitate as iron and aluminum sesquioxides forming colored spodic horizons denoted B_s.

Lessivage. Lessivage involves the vertical transport of particles and colloids of clay minerals. The downward horizons where the accumulation of the transported clays occurs are called argillic (denoted B_g) horizons. Usually, due to the swelling of clay minerals with water, the plugging of argillic horizons ensures an impermeabilization of lower horizons.

¹ Peat is the partly carbonized organic residue produced by decomposition of roots, trunks of trees, seeds, shrubs, grasses (reeds), ferns, mosses, and other vegetation.