Preface

Science and Engineering; Metals and Other Materials; the Microstructure

The German and Dutch languages have single, almost identical words for the field of “Materials Science and Engineering”: “Materialkunde” and “Materiaalkunde”, respectively. Thereby applications of materials serving mankind and the development of the corresponding basis of knowledge and understanding of nature have been indicated in a unified way. The intertwined nature of science and engineering is a decisive characteristic of this multidisciplinary field. Yet, as its title indicates, this book is devoted to materials science and much less to materials engineering. The reason for this restriction is twofold: firstly, a theoretical background is a prerequisite for any engineer to be successful, and thus any study in this field must start with providing a scientific basis, and, secondly, including a coverage of the synthesis and treatment of materials in practical applications would have made this book either too bulky or, to keep the amount of information offered manageable, too superficial.

The implication from the above is that it is intended to present a treatise on the basics of materials science that has a fundamental character. This may seem an impossible undertaking, as at the same time the book is meant to be used also in the beginning of a materials science and engineering study. For a start it implies that one largely has to abandon usage of mathematical techniques the reader is not familiar with yet. It is my conviction that this does not impede transmitting physical and chemical understanding. Of course, then some important results of advanced theories have to be introduced and accepted without proof, but this is no serious obstacle in order to develop a sound basis of the basics of the field. On the contrary, in this way one is best prepared for later to absorb separate, advanced courses on, say, quantum mechanics and materials thermodynamics and kinetics. If this book realizes these aspirations sufficiently satisfactorily, then this book will be used by the reader also at later stages of his/her study, because a fundamental background may be quickly grasped on the basis of what this book offers. Also therefore the material contained in the book is much more comprehensive than what can normally be offered in an introductory course on materials science. Or, phrased in another way, the book should provide useful preparation for reading and studying advanced textbooks on topics as “chemical bonding”, “diffusion” and “lattice defects” dealt with here in, only, chapters. There is no lack of such textbooks. But I do feel that there is a need for a book
as the present one in the light of my experience with existing introductory texts for
the field of materials science which I consider as often to be too superficial and too
phenomenological of nature.

Adopting the above philosophy I have made some, sometimes difficult, choices
in writing this book. This can be illustrated by what has been left out. For example,
I did not include detailed quantitative discussions on dislocation dynamics (Chap. 5),
the derivation of phase diagrams from the dependence of the Gibbs energy on com-
position (Chap. 7), the Kirkendall effect and the corresponding Darken treatment
(Chap. 8) or the (intrinsic) elastic anisotropy (Chap. 11). Those topics which do have
been treated in this book invariably are of paramount importance to the materials
scientist and have been dealt with in a fundamental way to an extent widely sur-
passing what can possibly be presented in a freshman’s course (e.g. the chapters on
“Crystallography” (Chap. 4), “Phase Transformations” (Chap. 9) and “Mechanical
Strength of Materials” (Chap. 11)). This does not impede at all the use of this book
in a beginner’s course already and especially makes this book useful throughout an
entire undergraduate and even graduate study as an introduction and solid background
against which more detailed monographs and specialized texts can be studied. Such
is the task of this book.

It is claimed here to offer “fundamentals of materials science”, and thus this is a
book about materials phenomena rather than materials. It has to be admitted that in
the text some apparent emphasis has been laid on metals as class of materials. This
should then be discussed as follows.

An obvious, not very important but not to be ignored, observation is the follow-
ing. The great majority of the naturally occurring elements in the Periodic System
(92) are metals; only a limited number of non-metal elements exist (about 15). It
is true that a few of these non-metals are of extreme importance for life on earth
(C, N, O and H). It is also true that life of man would not have the slightest resem-
blance with how it is now were it not for the application of metals. It may also be
relevant to remark here that the category of metals is in fact even much larger than
one may naively expect on the basis of the classical division of the elements given
above: any substance may be made metallic upon densification. Thus, hydrogen can
be made metallic under high pressure and silicon becomes metallic upon melting.
The background of this behaviour, i.e. why this is so, is discussed in Sect. 3.5 in this
book. This leaves unimpeded that other categories of materials, man-made or not, as
silicon-based components in microelectronics, ceramics, polymers and biomaterials,
are crucial materials as well. However, and now the cardinal argumentation follows,
understanding of the fundamental properties of materials is largely independent of
the type of material considered. The knowledge and science of crystallography, diffu-
sion, the thermodynamics and kinetics of phase transformations, etc. is not confined
to a specific class of materials.

Materials science has developed as a discipline from the time that metals were
considered as the perhaps most important materials in the world (see Cahn RW
This view needs no longer be held, but it explains that our knowledge on materials
behaviour has been developed with metallic materials as the type of material that was
subject of investigation. Material classes, metals, ceramics, polymers, biomaterials,
etc. most distinctly differ particularly in their way of synthesis (a topic not dealt with
at all in this book) and applications (polymers and biomaterials serve as examples).
However, their microstructure–property relationships are predominantly based on the
same concepts. Historically, such research on microstructure–property relationships was done first for metals. It should be recognized that concepts developed first for metals are needed and used now to characterize and explain the behaviour of newer classes of materials, as already demonstrated for ceramics, semiconductors and also polymers. This remains true observing strikingly specific properties associated with a certain material class; rubber elasticity serves as an example (see Sect. 11.6). New and future classes of materials will be dealt with on the basis of the same body of knowledge. The complexity of the materials classes appears to increase inversely with their “age”. The above leads to the conclusion that there is another reason why “metals” as a material class are of special importance to the materials scientist: metals provide the simplest class of materials where one can best start to investigate the concepts behind material behaviour.

Hence, in a book dedicated to materials science and less to engineering, as indicated above, it is justified and understandable that of the existing material classes the class of metals is emphasized, just as a simple consequence of most fundamental research on material behaviour having been done and still being done on metallic materials. This does not at all obstruct the transfer of fundamental, general knowledge on materials properties, which is the goal of this book.

The notion perhaps most typifying the field of materials science is the microstructure of a material. The microstructure of a material comprises all aspects of the atomic arrangement of the material that should be known in order to understand its properties. Confining ourselves to mostly solid, crystalline materials, the microstructure not in the first place concerns the idealized crystal structure, but in particular the imperfections, as the compositional inhomogeneity, the amount and distribution of phases, the grain size and shape and their parameter-distribution functions, the grain(crystal)-orientation distribution (called texture or preferred orientation), the grain boundaries and surface, the concentrations and distributions of defects as vacancies, dislocations, stacking and twin faults, and, not least, distortions as due to strains/stresses, etc. etc. (A special feature of this book is the chapter on “Analysis of the Microstructure; Analysis of Lattice Imperfections” (Chap. 6)). As may be anticipated from this still incomplete listing, the microstructure to a very large extent

---

1 As an anecdote, I here recall that decades ago I attended a conference in London where A. H. Cottrell, the author of a famous booklet on “Theoretical Structural Metallurgy” that I have cherished until today, presented a lecture on the role of metals in society. He showed, on the basis of sound references, that if one would have believed the predictions of those who said that polymers would take over the role of metals in the automotive industry, that one would have driven plastic cars already in the seventies (of the twentieth century, I have to add now). The message of his remark was: those who advocate the application and predict future importance, if not dominance, of a certain, new material class, extrapolate the properties of these materials into the future, but do as if the “classical” materials, against which the new materials are compared, are not the subject of on-going research and further development. In this sense new materials are chasing moving targets. Concerning the example discussed here: the emergence of high strength low alloy (HSLA) steels was ignored or not observed by the protagonists of plastics. This does not mean that plastics eventually cannot take over the role of metals in cars, but even today that has happened only partly. The point is: each time a new material emerges (quasicrystals, high-$T_c$ superconductors, carbon nanotubes, graphene, etc.) one is tempted to over exaggerate its possibilities for application. One should not forget, as a warning signal, that the, for a long time with great emphasis, much promoted idea of the development of the fully ceramic combustion engine has been buried, as it seems once and for all. A critical and yet open attitude towards any new, sensational presentation of a new material is in order.
determines the properties of a material. The central issue of materials science may be formulated as to develop *models that provide the relation between the microstructure and the properties*. Such an integrated and bridging the length scales (from micro to meso to macro) approach is THE feature distinguishing materials science from merely solid state physics and solid state chemistry. If this book succeeds in conveying also this message, I, as author, can be more than satisfied.

Science is not an abstract activity performed by flawless gods. At a number of places side remarks, as footnotes or “Intermezzi” and “Epilogues”, have been inserted which, for example, may refer to an illuminating historical development or point at an existing controversy. This has been done in an effort to indicate what the process of science involves, and that insight often is the result of a long struggle and not of unrestrictedly eternal value.

Stuttgart

August 2010

Eric J. Mittemeijer
Fundamentals of Materials Science
The Microstructure-Property Relationship Using Metals as Model Systems
Mittemeijer, E.J.
2011, XXI, 594 p., Hardcover
ISBN: 978-3-642-10499-2