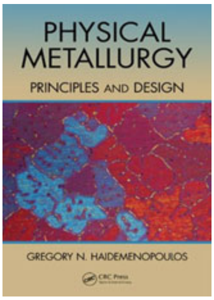

Physical Metallurgy: Principles and Design

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The author clearly regards crystallographic structures, phase diagrams and related metallurgical processes as topics which all who engage in the use of advanced metal alloys should study. Moreover, the author predicts that the ongoing development of computerised alloy design techniques may soon enable the design and production of optimised tailor-made metallic alloys to order.

The text is presented in three separate stages: (1) structure and change of structures through phase transformations; (2) plastic deformation, strengthening and mechanical properties; (3) the metallurgy of steels in general, followed by a computational confirmation of the design of advanced alloy steels. The main body of the text is supported by a synopsis and review questions at the end of each chapter.

The brief 'Introduction' (chapter 1) defines physical metallurgy as "... the part of metallurgical science, which deals with the shaping of the microstructure of metals and alloys, so they can obtain desirable properties required in technological applications" (page 1). 'Structure of Metals' (chapter 2) distinguishes between amorphous materials characterised by an irregular formation of atoms, and crystalline materials in which a regular and repeated arrangement of atoms, called a lattice, is observed. Fourteen possible configurations, known as Bravais lattices, feature in Fig. 2.2, only seven of which are commonplace, being further reduced to three for the purpose of discussion: the body-centred cubic (BCC), face-centred cubic (FCC) and hexagonal close-packed (HCP) lattices. See also the Miller index notation used to specify crystallographic directions. Note that greater prominence might have been given to the contributions of Lane, Sir William Bragg and his son Sir Lawrence Bragg to the development and proving of x-ray reflection (c. 1912–1913). Notwithstanding this quibble, the chapter is excellent in every respect, highlights being the crystal structure of metals, allotropy (changes in crystal structure with temperature/pressure changes), crystal structure effects, solid solutions, intermetallic compounds and intermediate phases, culminating in 'A First Look at the Microstructure of Alloys' (section 2.9) and 'Thermodynamics and Kinetics of Structure' (section 2.10).

'Structural Imperfections' (chapter 3) covers a wide range of factors which disrupt the

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uniformity of normally regular crystal lattice patterns (point defects: linear edge and screw). Surface imperfections that may occur at grain boundaries and three-dimensional voids are illustrated by excellent graphics. The numerous faults listed include perfect and partial dislocations, which are said to exist in all metals and alloys. Particular examples include stacking faults, cross slip, climb, jogs and kinks, all of which are discussed in detail.

'Alloy Thermodynamics and Phase Diagrams' (chapter 4) describes phase diagrams as maps which plot the temperature/composition of materials when in thermodynamic equilibrium (see Figs. 4.13 and 10.1, and the Fe–C equilibrium phase diagram on page 392, as this is the one that students often commit to memory. Suffice it also to note that these 'maps' are obtained by minimisation of the Gibbs free energy of the system, as explained on pages 91 and 05. Other sections include the free energy of solid solutions, and chemical potential and thermodynamic equilibrium. Binary systems, solid solubility and eutectic point are topics discussed in later pages.

'Diffusion' (chapter 5) explains how interstitial and/or substitutional atomic movement within the lattice depends on the type of solid solution. Octahedral, face-centred cubic and body-centred cubic examples are considered. Fink's first law of diffusion and the diffusion coefficient are covered in sections 5.3–5.5, while temperature dependence is addressed in section 5.6. Analytical solutions including partial differentiation of Laplace transformations plus numerical/computation methods are also presented.

'Phase Transformations' (chapter 6) identifies numerous important points about the heat treatment of metals: Figure 6.1, for example, illustrates how dissolution and precipitation in aluminium–copper alloys depend on the temperature and percentage copper content. While nucleation and growth transformations are considered in more general terms in section 6.2 and onward through a further 50 pages, nucleation strain energy/morphology and rate of current growth are clearly advanced topics addressed and supported by a liberal helping of mathematics, the complexity of the issue being impressively demonstrated by the copper–zinc alloy illustrated in figure 6.30 (page 228).

'Plastic Deformation and Annealing' (chapter 7) reminds/informs the reader that metals are inherently ductile (some more than others). Thus it is that copper (a metal with a face-centred cubic lattice) is amenable to relatively large deformations prior to eventual failure, whereas the ductility of structural steel (which has a body-centred cubic lattice) decreases considerably at temperatures below ambient. Section 7.2 identifies three mechanisms of plastic deformation: slip, twinning and habit planes, being associated forms. Subsequent sections consider deformation of single crystals by slip, deformation of polycrystals, strain hardening and dislocation multiplication. Annealing is described in section 7.7 as a process which releases the free energy of cold work (caused by cold rolling and deep drawing processes etc.) and thereby removes strain-hardening effects. While it is likely that all students studying the subject will have hands-on experience of hardening and annealing of steel specimens and later preparing them for microscopic examination, the text of this book elevates one's understanding to a higher scientific level.

'Strengthening Mechanisms' (chapter 8) recognises the fact that pure metals are inherently soft and do not provide the strength required for current engineering applications. This deficiency is of course overcome by adding suitable alloying elements to the mix, followed by the appropriate form of heat treatment, hence the author's interest in thermally activated slip and flow stress studies (see section 8.2 and associated mathematics on pages 301–306). This is followed by a five-point overview of strengthening mechanisms: lattice resistance, strain hardening, solid-solution strengthening, grain-boundary strengthening and precipitation strengthening (see table 8.5 on page 321 for a summary of attendant difficulties and limitations).

'Fracture, Fatigue and Creep of Metals' (chapter 9) focuses on the mechanical behaviour of metals in response to the application of mechanical loads, the nature of these loads being summarised in section 9.1. So-called brittle facture and ductile fracture are discussed in sections 21–22, where numerous examples of brittle failures that occurred between 1960 and 1980 are listed, briefly discussed and well illustrated in copious metallurgical detail. This is followed by a case study headed 'How did the notch toughness of steel contribute to the Titanic disaster?' (see page 343 for a 13-line account of the cause). Elements of fracture mechanics are introduced in sub-section 9.2.3, which surely warrants a full section index, after which attention shifts to fatigue in section 9.3.

Following a general introduction, the author states that there are two periods apparent in fatigue life: "The first period corresponds to the number of cycles which are required for the formation or initiation of a crack. The second period corresponds to the number of cycles required for the propogation of the crack to the critical size". The author also makes the point that there are two methodologies used to analyse and design structural components against fatigue failure. Suffice it to note that the procedure adopted for large welded structures differs from that used for machine parts such as shafts, gears and bearings. High- and low-cycle fatigue without pre-existing cracks (here called a strain life approach) explains how simple cyclic loading may be expressed in terms of a mean stress combined with an alternating stress, as all first/second-year students well know. While dealing with variable-amplitude loading, the Miner approach is described as a useful approximation. While the Coffin–Manson law (figure 9.22) and Basquin's law (figure 9.21) are all par for the course, the author's treatment of fatigue concludes with a consideration of a damage tolerance approach to the fatigue life of pre-existing cracks.

The three-stage concept of creep forms the basis of the discussion in section 9.4, where the effect of high temperature, plastic strain, glide and climb is explained in physical and metallurgical terms, with the effect of both stress and temperature levels being clearly shown on temperature–strain plots (figure 9.38). Topics considered include dislocation creep, diffusional flow and a section on creep fracture and creep life, concluding with a Larson–Miller plot and hints on how to design creep-resistant alloys.

'Physical Metallurgy of Steels' (Chapter 10) moves from the general to the specific, claiming that "[s]teel is the most important engineering material used by man" (page 389), albeit less suitable for aircraft on account of its density, i.e. weight per unit volume. However, in terms of usage,

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the author's claim is valid, as the following attributes show. Listed here in no particular order, steel possesses a diversity of micro-structure, allotropy of iron, alloying the potential for a favourable melting point. Steels also exist in three metallurgical states: as solid solutions of ferrite, austenite or martensite, pearlite and bainite, while carbides and nitrides play their part. Following a brief account of desirable objectives, 12 common alloying elements ranging from carbon to cobalt are listed and their contribution to the alloying process discussed. Suffice it to record a few remaining sub-headings: phase transformations in steels, hardenability, tempering of martensite, heat treatment of steel and finally a few case studies.

'Alloy Design' (chapter 10) describes the traditional development of new metal alloys as a very tedious process, a situation which has been alleviated to some extent by the advent of computational alloy design processes such as integrated computational materials engineering (ICME), with 'alloyneering' (based on analysis, simulation, validation, mapping and optimisation) being mentioned as one such example (see pages 443–445 for the related mathematics). The chapter and book conclude with section 11.4, headed 'Simulation Examples'.

Although this specialised text is – first and foremost – aimed at upwardly mobile students studying with a materials science department, the author cordially invites others to read this book and categorically states (page 2) that his aim is to help readers (of other persuasions) to understand the behaviour of metals subjected to mechanical and/or thermomechanical loads. The reviewer has greatly enjoyed and benefited from reading this useful, well-organised, authoritative book. All who are studying the strength of materials as a core subject will also find much in this book that is directly relevant to their studies: a step sideways perhaps, but one which will lead to a deeper understanding of their chosen subject.

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