THIRD EDITION

Engineering Materials 2

An Introduction to Microstructures, Processing and Design

Michael F Ashby
David R H Jones

B
H

Contents

General introduction ix

A. Metals 1

1. Metals 3
the generic metals and alloys; iron-based, copper-based, nickel-based, aluminium-based and titanium-based alloys; design data; examples

2. Metal structures 14
the range of metal structures that can be altered to get different properties: crystal and glass structure, structures of solutions and compounds, grain and phase boundaries, equilibrium shapes of grains and phases; examples

3. Equilibrium constitution and phase diagrams 25
how mixing elements to make an alloy can change their structure; examples: the lead–tin, copper–nickel and copper–zinc alloy systems; examples

4. Case studies in phase diagrams 35
choosing soft solders; pure silicon for microchips; making bubble-free ice; examples

5. The driving force for structural change 48
the work done during a structural change gives the driving force for the change; examples: solidification, solid-state phase changes, precipitate coarsening, grain growth, recrystallisation; sizes of driving forces; examples

6. Kinetics of structural change: I – diffusive transformations 61
why transformation rates peak – the opposing claims of driving force and thermal activation; why latent heat and diffusion slow transformations down; examples

7. Kinetics of structural change: II – nucleation 74
how new phases nucleate in liquids and solids; why nucleation is helped by solid catalysts; examples: nucleation in plants, vapour trails, bubble chambers and caramel; examples

8. Kinetics of structural change: III – displacive transformations 83
how we can avoid diffusive transformations by rapid cooling; the alternative – displacive (shear) transformations at the speed of sound; examples

9. Case studies in phase transformations 97
artificial rain-making; fine-grained castings; single crystals for semiconductors; amorphous metals; examples

10. The light alloys 108
where they score over steels; how they can be made stronger: solution, age and work hardening; thermal stability; examples

11. Steels: I – carbon steels 122
structures produced by diffusive changes; structures produced by displacive changes (martensite); why quenching and tempering can transform the strength of steels; the TTT diagram; examples

12. Steels: II – alloy steels 135
adding other elements gives hardenability (ease of martensite formation), solution strengthening, precipitation strengthening, corrosion resistance, and austenitic (f.c.c.) steels; examples

13. Case studies in steels 144
metallurgical detective work after a boiler explosion; welding steels together safely; the case of the broken hammer; examples

14. Production, forming and joining of metals 155
processing routes for metals; casting; plastic working; control of grain size; machining; joining; surface engineering; examples

B. Ceramics and glasses 173

15. Ceramics and glasses 175
the generic ceramics and glasses: glasses, vitreous ceramics, high-technology ceramics, cements and concretes, natural ceramics (rocks and ice), ceramic composites; design data; examples

16. Structure of ceramics 183
crystalline ceramics; glassy ceramics; ceramic alloys; ceramic micro-structures: pure, vitreous and composite; examples

17. The mechanical properties of ceramics 193
high stiffness and hardness; poor toughness and thermal shock resistance; the excellent creep resistance of refractory ceramics; examples

18. The statistics of brittle fracture and case study 202
how the distribution of flaw sizes gives a dispersion of strength: the Weibull distribution; why the strength falls with time (static fatigue); case study: the design of pressure windows; examples

19. Production, forming and joining of ceramics 213
processing routes for ceramics; making and pressing powders to shape; working glasses; making high-technology ceramics; joining ceramics; applications of high-performance ceramics; examples

20. Special topic: cements and concretes 227
historical background; cement chemistry; setting and hardening of cement; strength of cement and concrete; high-strength cements; examples

C. Polymers and composites 239

21. Polymers 241
the generic polymers: thermoplastics, thermosets, elastomers, natural polymers; design data; examples

22. The structure of polymers 251
giant molecules and their architecture; molecular packing: amorphous or crystalline?; examples

23. Mechanical behaviour of polymers 262
how the modulus and strength depend on temperature and time; examples

24. Production, forming and joining of polymers 279
making giant molecules by polymerisation; polymer "alloys"; forming and joining polymers; examples

25. Composites: fibrous, particulate and foamed 289
how adding fibres or particles to polymers can improve their stiffness, strength and toughness; why foams are good for absorbing energy; examples

26. Special topic: wood 306
one of nature's most successful composite materials; examples

D. Designing with metals, ceramics, polymers and composites 317

27. Design with materials 319
the design-limiting properties of metals, ceramics, polymers and composites; design methodology; examples

28. Case studies in design 326
1. Designing with metals: conveyor drums for an iron ore terminal
2. Designing with ceramics: ice forces on offshore structures
3. Designing with polymers: a plastic wheel
4. Designing with composites: materials for violin bodies

29. Engineering failures and disasters – the ultimate test of design 352
Introduction
Case study 1: the Tay Bridge railway disaster – 28 December 1879
Case study 2: the Comet air disasters – 10 January and 8 April 1954
Case study 3: the Eschede railway disaster – 5 June 1998
Case study 4: a fatal bungee-jumping accident

Appendix 1 Teaching yourself phase diagrams 380
Appendix 2 Symbols and formulae 434
References 442

Index 445