

Contents

| | | |
|----------|---|----------|
| A | Fundamentals of ferrous materials | 3 |
| | H. BERNS | |
| A.1 | Constitution | 3 |
| A.1.1 | Pure iron | 5 |
| A.1.2 | Iron-carbon | 9 |
| A.1.2.1 | The iron-cementite system | 11 |
| A.1.2.2 | The iron-graphite system | 13 |
| A.1.3 | Alloyed iron | 14 |
| A.2 | Microstructure | 21 |
| A.2.1 | Near-equilibrium microstructure | 26 |
| A.2.1.1 | Steel | 26 |
| A.2.1.2 | Cast iron | 31 |
| A.2.2 | Non-equilibrium microstructure | 36 |
| A.2.2.1 | Shaping | 37 |
| A.2.2.2 | Austenite transformation | 38 |
| A.2.2.3 | Post-quenching morphology | 42 |
| A.2.2.4 | Reheating of quenched microstructures | 48 |
| A.2.3 | Morphology of cementite and graphite | 53 |
| A.3 | Heat treatment | 57 |
| A.3.1 | Annealing processes | 58 |
| A.3.1.1 | Baking | 58 |
| A.3.1.2 | Stress-relief annealing | 58 |
| A.3.1.3 | Soft annealing of steel | 59 |
| A.3.1.4 | Soft annealing of cast iron | 62 |
| A.3.1.5 | Normalising | 62 |
| A.3.1.6 | Temper annealing of cast iron | 63 |
| A.3.1.7 | Solution annealing | 63 |
| A.3.1.8 | Homogenising | 63 |
| A.3.2 | Hardening and related processes | 64 |
| A.3.2.1 | Hardening | 64 |
| A.3.2.2 | Tempering | 68 |
| A.3.2.3 | QT treatment | 69 |
| A.3.2.4 | Transformation in the bainite range | 70 |
| A.3.3 | Surface layer treatment/Coating | 71 |

VIII Contents

| | | |
|---------|--|-----|
| A.3.4 | Side-effects | 72 |
| A.3.4.1 | Thermal side-effects | 73 |
| A.3.4.2 | Thermochemical side-effects | 74 |
| A.4 | Properties | 79 |
| A.4.1 | Mechanical properties | 79 |
| A.4.1.1 | Loading | 79 |
| A.4.1.2 | Behaviour of steel | 82 |
| A.4.1.3 | Behaviour of grey cast iron | 99 |
| A.4.1.4 | Behaviour of white cast iron | 102 |
| A.4.2 | Tribological properties | 103 |
| A.4.2.1 | Friction | 104 |
| A.4.2.2 | Wear | 106 |
| A.4.3 | Chemical properties | 109 |
| A.4.3.1 | Wet corrosion | 109 |
| A.4.3.2 | High-temperature corrosion | 115 |
| A.4.4 | Special physical properties | 117 |
| A.4.4.1 | Magnetic properties | 117 |
| A.4.4.2 | Thermal expansion | 120 |
| A.4.4.3 | Conductivity | 121 |

B Ferrous materials and their applications 125

| | | |
|------------|---|-----|
| B.1 | Materials for general applications | 125 |
| B.1.1 | Unalloyed structural steels | 125 |
| H. BERNIS | | |
| B.1.1.1 | Properties | 126 |
| B.1.1.2 | Grades and applications | 134 |
| B.1.2 | Cast iron | 144 |
| W. THEISEN | | |
| B.1.2.1 | Composition of grey cast iron | 144 |
| B.1.2.2 | Cast iron with flake graphite | 147 |
| B.1.2.3 | Cast iron with spheroidal graphite | 150 |
| B.1.2.4 | Cast iron with vermicular graphite | 152 |
| B.1.2.5 | Malleable cast iron | 154 |
| B.1.2.6 | Processing and applications of cast iron | 157 |
| B.2 | High-strength materials | 165 |
| B.2.1 | Weldable rolled steels | 165 |
| H. BERNIS | | |
| B.2.1.1 | Fine-grain steels | 165 |
| B.2.1.2 | Multi-phase steels | 168 |
| B.2.1.3 | Applications of weldable steels | 175 |
| B.2.1.4 | Lightweight steels | 182 |
| B.2.1.5 | Pearlitic rolled steels | 184 |
| B.2.2 | Steels treated from the forging temperature | 184 |
| B.2.2.1 | Martensitic steels | 185 |
| B.2.2.2 | Ferritic-pearlitic steels | 188 |

| | | |
|------------|---|-----|
| B.2.3 | Structural steels for full heat treatment | 190 |
| B.2.3.1 | QT steels | 190 |
| B.2.3.2 | Ultrahigh-strength steels | 198 |
| B.2.3.3 | Hard steels | 203 |
| B.2.4 | Cast iron for full heat treatment | 207 |
| W. THEISEN | | |
| B.2.4.1 | Quenching and tempering | 207 |
| B.2.4.2 | Transformation in the bainite range / ADI | 208 |
| B.3 | Materials for surface layer treatments | 217 |
| H. BERNS | | |
| B.3.1 | Materials for surface-hardening | 217 |
| B.3.1.1 | Process engineering aspects of surfacehardening | 217 |
| B.3.1.2 | Materials and the surface layer | 220 |
| B.3.1.3 | Applications | 223 |
| B.3.2 | Nitriding steels | 224 |
| B.3.2.1 | Process engineering aspects of nitriding | 224 |
| B.3.2.2 | Materials and the surface layer | 228 |
| B.3.2.3 | Applications | 232 |
| B.3.3 | Case hardening steels | 234 |
| B.3.3.1 | Process engineering aspects of case hardening | 234 |
| B.3.3.2 | Materials and the surface layer | 241 |
| B.3.3.3 | Applications | 246 |
| B.4 | Tools for processing minerals | 251 |
| W. THEISEN | | |
| B.4.1 | Loading and material concepts | 251 |
| B.4.1.1 | Hard phases | 252 |
| B.4.1.2 | Metal matrix | 254 |
| B.4.2 | Tools made of hot-formed steel | 256 |
| B.4.3 | Cast tools | 259 |
| B.4.3.1 | Pearlitic white cast iron | 259 |
| B.4.3.2 | Martensitic nickel white cast iron | 260 |
| B.4.3.3 | Martensitic chromium white cast iron | 261 |
| B.4.4 | Coated tools | 264 |
| B.4.4.1 | Hard-facing | 264 |
| B.4.4.2 | Powder metallurgical coatings | 267 |
| B.4.4.3 | Composite casting | 269 |
| B.5 | Tools for processing materials | 273 |
| W. THEISEN | | |
| B.5.1 | Cold-work tools | 274 |
| B.5.1.1 | Properties | 277 |
| B.5.1.2 | Coated tools | 283 |
| B.5.1.3 | Applications of cold-work tools | 288 |
| B.5.2 | Tools for processing plastics | 291 |
| B.5.3 | Hot-work tools | 293 |
| B.5.3.1 | Properties | 294 |

| | | |
|------------|---|------------|
| B.5.3.2 | Applications | 296 |
| B.5.4 | Tools for machining applications | 299 |
| B.5.4.1 | Properties | 300 |
| B.5.4.2 | Applications | 303 |
| B.6 | Chemically resistant materials | 309 |
| H. BERNIS | | |
| B.6.1 | General information | 309 |
| B.6.1.1 | Alloying concept | 309 |
| B.6.1.2 | Matrix properties | 311 |
| B.6.2 | Stainless steels | 317 |
| B.6.2.1 | Properties | 319 |
| B.6.2.2 | Applications | 331 |
| B.6.3 | Heat-resistant steels | 336 |
| B.6.3.1 | Properties | 336 |
| B.6.3.2 | Applications | 339 |
| B.6.4 | Cast iron | 341 |
| B.6.4.1 | Ferritic cast iron | 341 |
| B.6.4.2 | Austenitic cast iron | 342 |
| B.6.4.3 | White cast iron / carbide-rich steels | 344 |
| B.7 | Creep-resistant materials | 349 |
| H. BERNIS | | |
| B.7.1 | Properties | 352 |
| B.7.1.1 | Normalised as well as QT steels | 352 |
| B.7.1.2 | Austenitic steels | 357 |
| B.7.1.3 | Cast iron | 360 |
| B.7.2 | Applications | 360 |
| B.7.2.1 | Steam power plants | 360 |
| B.7.2.2 | Gas turbines | 362 |
| B.7.2.3 | Estimation of the service life | 363 |
| B.7.2.4 | Petrochemistry | 365 |
| B.7.2.5 | Valves | 365 |
| B.8 | Functional materials | 369 |
| H. BERNIS | | |
| B.8.1 | Magnetically soft materials | 369 |
| B.8.2 | Magnetically hard materials | 373 |
| B.8.3 | Non-magnetisable materials | 375 |
| B.8.4 | Materials with a special thermal expansion | 376 |
| B.8.5 | Materials with a shape memory | 378 |
| B.8.6 | Electrical resistance heating alloys | 380 |
| C | Appendix | 383 |
| C.1 | Designation systems for steel and cast iron | 383 |
| W. THEISEN | | |
| C.1.1 | Standardisation | 383 |
| C.1.2 | Designations for steels and cast steels | 384 |

| | |
|--|------------|
| Unalloyed steels | 386 |
| Alloyed steels | 386 |
| High-alloy steels | 387 |
| High-speed tool steels | 387 |
| C.1.3 Designation of cast irons | 388 |
| C.2 A brief discourse on the history of iron | 392 |
| H. BERNIS | |
| C.2.1 From a bloomery to a shaft furnace | 392 |
| C.2.2 The spread of iron-making | 395 |
| C.2.3 Cast iron and the fining process | 395 |
| C.2.4 Mild steel | 397 |
| C.2.5 Ferrous materials | 398 |
| C.3 Bibliography for figures and tables | 400 |
| Keyword Index | 403 |
| List of alloying and tramp elements | 416 |