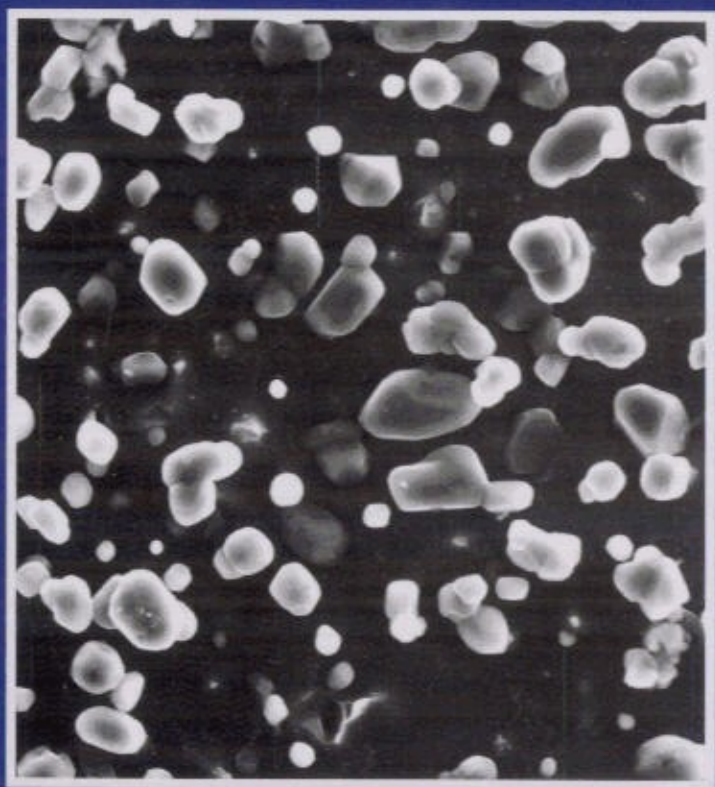




CASTING ALUMINUM ALLOYS



VADIM S. ZOLOTOREVSKY

NIKOLAI A. BELOV

MICHAEL V. GLAZOFF

CONTENTS

<i>Preface</i>	<i>ix</i>
<i>Notations</i>	<i>xiii</i>

1. Alloying Elements and Dopants: Phase Diagrams	1
1.1 The Role of Alloying Elements and Dopants: Basic Alloy Systems	1
1.2 Phase Diagrams of Ternary Systems	14
1.2.1 The Al–Be–Fe system	14
1.2.2 The Al–Be–Si system	15
1.2.3 The Al–Ce–Cu system	16
1.2.4 The Al–Ce–Fe system	18
1.2.5 The Al–Ce–Ni system	20
1.2.6 The Al–Ce–Si system	21
1.2.7 The Al–Cr–Fe system	22
1.2.8 The Al–Cr–Mg system	23
1.2.9 The Al–Cr–Mn system	24
1.2.10 The Al–Cr–Si system	26
1.2.11 The Al–Cu–Fe system	26
1.2.12 The Al–Cu–Mg system	29
1.2.13 The Al–Cu–Mn system	32
1.2.14 The Al–Cu–Ni system	34
1.2.15 The Al–Cu–Si system	36
1.2.16 The Al–Cu–Zn system	36
1.2.17 The Al–Fe–Mg system	38
1.2.18 The Al–Fe–Mn system	39
1.2.19 The Al–Fe–Ni system	41
1.2.20 The Al–Fe–Si system	42
1.2.21 The Al–Mg–Mn system	45
1.2.22 The Al–Mg–Si system	45
1.2.23 The Al–Mg–Zn system	47
1.2.24 The Al–Mn–Ni system	49
1.2.25 The Al–Mn–Si system	53
1.2.26 The Al–Ni–Si system	54
1.3 Phase Diagrams of Four-Component Systems	55
1.3.1 The Al–Be–Fe–Si phase diagram	56
1.3.2 The Al–Cu–Fe–Mg system	58
1.3.3 The Al–Cu–Fe–Mn system	58
1.3.4 The Al–Cu–Fe–Ni system	60
1.3.5 The Al–Cu–Fe–Si system	62
1.3.6 The Al–Cu–Mg–Mn system	64

1.3.7	The Al–Cu–Mg–Si system	64
1.3.8	The Al–Cu–Mg–Zn system	66
1.3.9	The Al–Fe–Mg–Mn system	68
1.3.10	The Al–Fe–Mg–Si system	70
1.3.11	The Al–Fe–Mn–Si system	74
1.3.12	The Al–Fe–Ni–Si system	77
1.3.13	The Al–Mg–Mn–Si system	79
1.3.14	The Al–Mg–Ni–Si system	79
1.4	Five-Component Phase Diagrams	81
1.4.1	The Al–Fe–Cu–Mg–Si system	85
1.4.2	Five-component Systems with manganese	91
2.	Structure and Microstructure of Aluminum Alloys in As-Cast State	95
2.1	Phase Diagrams, Thermodynamics, and Alloy Microstructure	95
2.2	Equilibrium Thermodynamics and Its Development	97
2.2.1	Classical equilibrium thermodynamics	97
2.2.2	Equilibrium thermodynamics of concentrationally non-uniform systems	98
2.3	Brief Description of Solidification Microstructure Evolution in Casting Aluminum Alloys via the “Phase-Field” Approach	101
2.3.1	Phase-field approach applied to solidification	102
2.3.2	Dendritic solidification of pure metals	102
2.3.3	Phase-field model for solidification of eutectic alloys ¹⁴	104
2.3.4	Solidification microstructure calculations: perspectives and future work	106
2.4	Quantitative Characteristics of Alloy Structure and Methods of its Evaluation	107
2.5	Non-Equilibrium Solidification of Binary Alloys	114
2.5.1	Microsegregation	115
2.5.2	Influence of cooling rate upon solidification and formation of constituent particles of secondary (excessive) phases	128
2.6	Non-Equilibrium Solidification of Multi-Component Alloys	134
2.6.1	Non-equilibrium phase diagrams of multicomponent systems	134
2.6.2	Microsegregation in three-component and industrial aluminum alloys	145
2.7	Microstructure of Cast Aluminum Alloys	154
2.8	Substructure of Casting Aluminum Alloys	162
2.8.1	Types of dislocation structures in as-cast aluminum alloys of different systems	162
2.8.2	The influence of solidification conditions upon dislocation microstructure	166
2.8.3	The mechanisms of formation of dislocation microstructures in cast aluminum alloys	171
2.8.4	Decomposition of aluminum solid solution in the process of alloy cooling after the completion of solidification	177

3. Influence of Heat Treatment Upon Microstructure of Casting Aluminum Alloys	183
3.1 Homogenizing Heat Treatment	184
3.1.1 Dissolution of non-equilibrium constituent particles in the course of homogenization	184
3.1.2 Elimination of microsegregation during homogenization	200
3.1.3 Fragmentation and spheroidization of constituent particles	213
3.1.4 Changes of grain and dislocation microstructure of aluminum solid solution in the course of homogenization	222
3.1.5 Decomposition of aluminum solid solution in the process of isothermal heat treatment before quenching	230
3.1.6 Development of porosity during homogenization	240
3.2 Aging After Casting and Quenching	240
4. Dependence of Castability and Mechanical Properties on Composition and Microstructure of Aluminum Alloys	247
4.1 Castability	247
4.1.1 General characterization of castability	247
4.1.2 Concentration dependence of casting properties	258
4.2 Mechanical Properties	262
4.2.1 Geometry of elongation diagrams for as-cast and quenched aluminum alloys, and its connection to the structural transformations accompanying deformation	266
4.2.2 Quantitative analysis of relations between tensile mechanical properties and structural characteristics of castings	280
4.2.3 Calculations of mechanical properties of castings using the totality of microstructural characteristics	295
4.2.4 The influence of casting microstructure upon fracture toughness and fatigue properties	302
4.2.5 Some regularities in changes of mechanical properties with alloy chemical composition	311
5. Industrial Casting Aluminum Alloys	327
5.1 Al–Si Alloys	327
5.1.1 General characterization of Al–Si alloys	327
5.1.2 Industrial 4xx and 3xx casting alloys without copper and zinc (“copper-less” alloys)	336
5.1.3 Industrial Al–Si alloys with copper and zinc	351
5.1.4 Engine piston Al–Si alloys	367
5.2 Alloys on the Basis of the Al–Cu System	376
5.3 Al–Mg and Al–Mg–Zn Alloys	386
5.3.1 General characteristic of Al–Mg alloys	386
5.3.2 Industrial Al–Mg and Al–Mg–Zn alloys	390

6. New Alloys	397
6.1 Alloys with Small Amounts of Eutectic	397
6.2 General Principles of Alloying for Eutectic Materials	405
6.3 High-Strength Alloy AZ6N ₄ and ATs ₇ Mg ₃ N ₄ (734)	418
6.4 Alloys Doped with Transition Metals for Improved Thermal Stability	425
6.5 Alloys with Small Amounts of Silicon (<4%Si)	441
<i>Literature</i>	449
Appendix 1 Compositions of Standard Casting Aluminum Alloys	461
Appendix 2 Principal Characteristics of Binary Phase Diagrams Closer to Aluminum Side	487
Appendix 3 Guaranteed Mechanical Properties of Standard Russian Aluminum Alloys	491
Appendix 4 Recommended Heat Treatments of Standard Russian Casting Aluminum Alloys	499
Appendix 5 Data on Fracture Toughness and Shock Toughness, Fatigue Life, Characteristics of Thermal Stability, Corrosion Resistance, and Castability of Standard Al–Si Alloys	507
Appendix 6 Derivation of Equations Describing Uniaxial Tensile Testing in Finite Deformations	511
A.6.1 The Case of Infinitesimally Small Deformations	513
A.6.2 The Case of Finite Deformations	515
<i>Index</i>	523