

PART I

THE PHYSICAL ASPECTS OF CASTING:
MOLD DESIGN, PRODUCTION, AND MATERIALS

CHAPTER 1. INTRODUCTION	3
1-1 What is a metal casting?	3
1-2 A survey of the foundry industry	6
1-3 The casting problem defined	7
1-4 The design and production of the mold	8
1-5 Melting, refining, and pouring of liquid metal	9
CHAPTER 2. MECHANISM AND RATE OF SOLIDIFICATION OF METALS AND ALLOYS	11
2-1 General remarks	11
2-2 Solidification of pure metals	11
2-3 Nucleation and growth in alloys	14
2-4 The solidification of actual castings	19
2-5 The effects of mold material and alloy composition upon freezing pattern (feeding resistance)	26
2-6 The rate of solidification	32
2-7 Correlation of analog computer data with Chvorinov formula and experimental results	37
CHAPTER 3. RISER DESIGN AND PLACEMENT	41
3-1 General remarks	41
3-2 Riser curves for steel	43
3-3 Naval Research Laboratory method of riser calculation	45
3-4 Feeding distance	50
3-5 Other effects of complex sections and designs	56
3-6 Effect of chills	58
3-7 Application of risering principles to complex castings	60
3-8 Riser of gray iron	61
3-9 Riser of brass, aluminum, and magnesium	62
CHAPTER 4. GATING DESIGN	66
4-1 Introduction	66
4-2 Law of continuity	67
4-3 Bernoulli's equation	67
4-4 Example of vertical gating	69
4-5 Aspiration effects	70
4-6 Prevention of aspiration	72

4-7	Bottom gating systems	74
4-8	Function of the horizontal gating system	75
4-9	Aspiration effects at points of change in metal stream direction	76
4-10	Platelike castings	77
4-11	Complex chunky castings	78
4-12	Stack molds	80
4-13	Dross trap system	81
CHAPTER 5. METAL FLUIDITY		87
5-1	General	87
5-2	Measurement of fluidity	87
5-3	The sand-mold fluidity spiral	88
5-4	Typical fluidity curves	91
5-5	Effect of metal chemistry	91
5-6	Suction-tube data	93
5-7	Summary of spiral and suction-tube data	94
5-8	Application of fluidity data to casting problems	95
5-9	Calculation of liquidus	96
CHAPTER 6. STRESS-STRAIN RELATIONS IN CASTINGS DURING COOLING AND HEAT TREATMENT		99
6-1	Introduction	99
6-2	Stress-strain relations as a function of temperature	99
6-3	Hot tears: mechanism and experimental evidence	103
6-4	Relation of hot tears to chemical composition and phase diagram	105
6-5	Relation of hot tears to mold constraints casting and to the interaction between sections	108
6-6	Cracks, residual stresses, stress relief	111
6-7	Quantitative discussion of expansion and contraction	113
6-8	Measurement of residual stresses	114
6-9	Case histories	115
6-10	Control of residual stresses	119
6-11	Stress relief	120
6-12	Selection of temperature and time cycles for stress relief	124
6-13	Relation between hot tears and residual stresses	128
6-14	Weldments	128
6-15	Summary	129
CHAPTER 7. MOLD PRODUCTION AND PATTERN CONSTRUCTION		134
7-1	The general problem	134
7-2	Green-sand molding	136
7-3	Dry-sand molding	139
7-4	Core-sand molding	139
7-5	The CO ₂ process	140
7-6	Shell molding	143
7-7	Investment casting	145

7-8	Permanent-mold centrifugal casting	146
7-9	Die casting	148
7-10	Pattern design and construction	148
CHAPTER 8. MOLD MATERIALS; REACTIONS AT REFRACTORY-METAL INTERFACE		152
8-1	Introduction	152
8-2	Review of crystal structures and bonding forces	153
8-3	Silica and silicate structures	158
8-4	Clays	162
8-5	The clay-water-silica bond	164
8-6	Hydraulic bonds	165
8-7	Other silicates	166
8-8	Organic bonds	168
8-9	Green sand	168
8-10	Dry sand	173
8-11	Core sand	175
8-12	Shell sand	175
8-13	Investment molds	175
8-14	Permanent molds, die casting	176
8-15	Mold-metal interface reactions	176
8-16	Refractory-metal reactions	181
CHAPTER 9. MOLD DESIGN AND PROCESSING METHOD. OPTIMIZATION OF CASTING DESIGN		185
9-1	General	185
9-2	Choice of molding materials and methods for a given design	185
9-3	Balancing costs	187
9-4	Fluidity and gating	190
9-5	Risering	190
9-6	Internal stresses and defects	191
9-7	Cause and cure of common casting defects	191
9-8	Optimizing casting design for maximum strength and ease of processing	194

PART II

**THE CHEMISTRY OF LIQUID METAL;
CONTROL OF COMPOSITION, MELTING, AND REFINING**

CHAPTER 10. GASES IN METALS		205
10-1	General	205
10-2	Gases in metals	206
10-3	Hydrogen	206
10-4	Removal of hydrogen	211
10-5	Nitrogen	214

10-6	Complex gases. CO in steel	220
10-7	Complex gases in copper and copper alloys	223
10-8	General summary of gas control	230
10-9	Vacuum melting	231
10-10	Inclusions	233
10-11	Inoculating effects. Ladle additions	237
CHAPTER 11. CONTROL OF CHEMICAL COMPOSITION		240
11-1	General	240
11-2	Carbon	240
11-3	Manganese	243
11-4	Silicon	245
11-5	Phosphorus	246
11-6	Sulfur	248
11-7	Alloys	249
11-8	Nickel-base alloys	252
11-9	Copper-base alloys	253
11-10	Aluminum-base alloys	255
11-11	Magnesium-base alloys	255
11-12	Zinc-base alloys	255
CHAPTER 12. SELECTION AND CONTROL OF MELTING PROCESSES		263
12-1	General	263
12-2	Overall comparison of melting furnaces	267
12-3	Chemical control in cupola melting	268
12-4	Chemical control in the air furnace and the open hearth	273
12-5	Chemical control in arc melting	275
12-6	Chemical control in induction furnaces	279
12-7	The converter	279
12-8	Duplex and triplex processes	280
12-9	Nonferrous melting furnaces	280
CHAPTER 13. REVIEW OF METALLURGICAL CALCULATIONS		284
13-1	General	284
13-2	Review of units	285
13-3	The gas laws	286
13-4	Mass and energy balances (first law of thermodynamics)	288
13-5	Combined application of the first and second laws of thermodynamics	296
13-6	Gas-liquid equilibrium	303
13-7	Slag-metal equilibria	306
13-8	Combined phase-diagram and equilibrium-constant calculations	306
APPENDIX I		309
APPENDIX II		312
INDEX		319