Contents

Preface to the Second Edition xi
Preface to the First Edition xv
Contributors xix
Acknowledgements xxi

1 Introduction 1
1.1 The Flat Rolling Process 1
1.2 The Hot Rolling Process 1
1.3 Continuous Casting 7
1.4 Mini-Mills 8
1.5 The Cold Rolling Process 10
1.6 The Warm Rolling Process 13
1.7 Further Reading 15
1.8 Conclusion 15

2 History of Hot Strip Mills 17
2.1 Hot Strip Mill Evolution 17
2.2 Early Hot Strip Mills 19
2.3 Early Steckel Mills 19
2.4 Generation I Hot Strip Mills (USA) 19
2.5 Generation II Hot Strip Mills (USA) 20
2.6 Other Generation I and II Hot Strip Mills 21
2.7 Generation III – Coil Box Hot Strip Mills 22
2.8 Thin Slab Hot Strip Mills 22
2.9 Newer Generation II Hot Strip Mills 23
2.10 Modern Steckel Mills 24
2.11 Hot Mill Electrical Systems 24
2.12 Hot Strip Mill Innovations 26
2.13 Revamped Hot Strip Mills 28

3 Roll Design 31
3.1 Introduction 31
3.2 General Overview 31
3.3 Historical Development of Rolls for Rolling Mills 32
3.4 Roll Wear 33
3.5 Friction and Wear 35

4 Flat Rolling – A General Discussion **39**
4.1 The Flat Rolling Process **39**
4.2 The Physical Events Before, During and After the Pass **44**
4.3 The Metallurgical Events Before and After the Rolling Process **50**
4.4 Limitations of the Flat Rolling Process **52**
4.5 Conclusion **55**

5 Mathematical and Physical Modelling of the Flat Rolling Process **57**
5.1 A Discussion of Mathematical Modelling **57**
5.2 A Simple Model **61**
5.3 1D Models **67**
5.4 Refinements of the Orowan Model **72**
5.5 The Effect of the Inertia Force **76**
5.6 The Predictive Ability of the Mathematical Models **78**
5.7 The Friction Factor in the Flat Rolling Process **80**
5.8 Extremum Principles **89**
5.9 Comparison of the Predicted Powers **92**
5.10 The Development of the Mechanical Attributes of the Rolled Strip **93**
5.11 Miscellaneous Parameters and Relationships in the Flat Rolling Process **105**
5.12 How a Mathematical Model Should Be Used **109**
5.13 Conclusions **111**

6 An Advanced Finite Element Model of the Flat, Cold Rolling Process **113**
6.1 Introduction **114**
6.2 Modelling the Flat Rolling Process **115**
6.3 Experiments **117**
6.4 Results **118**
6.5 Comparison of the Experimental and Numerical Results **120**
6.6 Conclusion **123**
6.7 Acknowledgements **123**

7 Flat Rolling – Simulation and Reduction of Local Buckles in Cold Rolling **125**
7.1 Introduction **125**
7.2 Strain Rate Based Strip 3D Deformation Model **126**
7.3 Work Roll Thermal Crown Model **132**
7.4 Roll Stack Deformation Model **132**
7.5 Stress Unloading Model **136**
7.6 Local Buckling Threshold Model **137**
7.7 Local Buckling Shape Model **139**
7.8 Flow Chart of the Main Program **141**
7.9 Model Tuning and Verification **143**
7.10 User Interface **143**
7.11 Base Case for Local Shape Defect Simulation **144**

7.12 Effects of Entry Strip Profile Ridge 145
7.13 Effect of Local Yield Stress Drop 150
7.14 Roll Cooling Nozzle Clog or Work Roll Crown Ridge Effect 153
7.15 Identification of Causes of Local Buckles 154
7.16 Predicting Limiting Values for Factors Causing Local Buckles 156
7.17 Reduction of Local Buckles 161

8 Material Attributes 163
8.1 Introduction 163
8.2 Recently Developed Steels 164
8.3 Steel and Aluminium 169
8.4 The Independent Variables 170
8.5 Traditional Testing Techniques 171
8.6 Potential Problems Encountered During the Testing Process 176
8.7 The Shape of Stress–Strain Curves 180
8.8 Mathematical Representation of Stress–Strain Data 184
8.9 Choosing a Stress–Strain Relation for Use in Modelling the Rolling Process 190
8.10 Summary 191

9 Tribology 193
9.1 Tribology – A General Discussion 193
9.2 Friction 194
9.3 Determining the Coefficient of Friction or the Friction Factor 205
9.4 Lubrication 222
9.5 Dependence of the Coefficient of Friction or the Roll Separating Force on the Independent Variables 241
9.6 Heat Transfer 252
9.7 Roll Wear 258
9.8 Nanotribology 260
9.9 Conclusions 261

10 Applications and Sensitivity Studies 267
10.1 The Sensitivity of the Predictions of the Flat Rolling Models 267
10.2 A Comparison of the Power Predictions Required for Plastic Deformation of the Strip 271
10.3 The Roll Pressure Distribution 272
10.4 The Statically Recrystallized Grain Size 273
10.5 The Critical Strain 274
10.6 The Hot Strength of Steels – Shida's Equations 275

11 Hot Rolling of Aluminium 279
11.1 Introduction 279
11.2 Hot Rolling Process 281
11.3 Heat Transfer 283
11.4 Deformation 285

11.5 Microstructure Changes During Hot Rolling 285
11.6 Summary 288

12 Temper Rolling 291
12.1 The Temper Rolling Process 291
12.2 The Mechanism of Plastic Yielding 291
12.3 The Effects of Temper Rolling 293
12.4 Mathematical Models of the Temper Rolling Process 293
12.5 Summary 302

13 Severe Plastic Deformation – Accumulative Roll Bonding 303
13.1 Introduction 303
13.2 Manufacturing Methods of Severe Plastic Deformation 303
13.3 A Set of Experiments 308
13.4 Results and Discussion 309
13.5 The Phenomena Affecting the Bonds 314
13.6 A Potential Industrial Application: Tailored Blanks 316
13.7 A Combination of ECAP and ARB 317
13.8 Conclusions 321

14 Roll Bonding 323
14.1 Introduction 323
14.2 Material, Equipment, Sample Preparation and Parameters 325
14.3 Results and Discussion 326
14.4 Examination of the Interface 330
14.5 The Phenomenon of Bonding 334
14.6 Conclusions 336

15 Flexible Rolling 337
15.1 Introduction 337
15.2 Material, Equipment, Procedure and Sample Preparation 340
15.3 Results and Discussion 341
15.4 Predictions of a Simple Model 344
15.5 Strain at Fracture 345
15.6 Conclusions 348

16 Problems and Solutions 349
Part 1 Problems 349
Part 2 Solutions 369

Appendix 379
References 387

For color versions of select figures, please refer to http://booksite.elsevier.com/9780080994185