Contents

1 The Basis of Sheet Metal Forming Technology 1
1.1 The Development of Stamping Technology 2
1.2 The Basics of Sheet Metal Forming 4
1.2.1 The Process of Traditional Cold Stamping 4
1.2.2 The Cold Stamping Tool 5
1.2.3 Stamping Press 7
1.2.4 The Production Process of Stampings 9
1.3 Materials for Cold Stamping and Its Formability 11
1.3.1 Requirements on Materials for Cold Stamping 11
1.3.2 The Formability of Materials 12
1.4 Summary 17
References 18

2 Hot Stamping Technology and the Main Equipment 19
2.1 The Hot Stamping Technology of High Strength Steel 19
2.1.1 Brief Introduction of Hot Stamping Technology 19
2.1.2 Hot Stamping Process 21
2.1.3 Finite Element Simulation Analysis of Hot Stamping Technology 28
2.1.4 The Research Status of Hot Stamping 30
2.2 Hot Stamping Production Lines and the Key Equipments 32
2.2.1 Continuous Ring Heating Furnace 33
2.2.2 High-Temperature Resistant Robot Arm and Automatic Transfer Device for Loading and Unloading 35
2.2.3 Key Technologies for Design and Manufacture of Hot Stamping Dies 36
2.2.4 High-Speed Hydraulic Press for Hot Stamping 38

2.2.5 Central Intelligence Control Automatic Integrated System. 39
2.2.6 Subsequent Shot Blasting, Trimming, and Punching Equipment 40
2.3 Summary 42
References. 42

3 Performance of Hot Stamping High Strength Steel (HSS) Technology 45
3.1 Process and Principle of Hot Stamping HSS 45
3.1.1 Hot Stamping Plate 45
3.1.2 Hot Stamping Technology and Mechanism 48
3.2 Research in the basic technology of hot stamping 50
3.2.1 Mechanical Properties of Hot Stamping Steel 50
3.2.2 Effect of Heating Temperature on the Mechanical Properties of Hot Stamping Steel. 53
3.2.3 Effect of Holding Time on the Mechanical Properties of Hot Stamping Steel Plate 57
3.2.4 Effects of Cooling Rate on the Mechanical Behavior of Hot Stamping Steel Plate 59
3.3 The Study of Hot Stamping Material Toughness Process Experiment 63
3.3.1 Hot Stamping Steel Strength-Toughness Tempering Process 63
3.3.2 Hot Stamping Steel Strength-Toughness High Temperature Quenching Process 70
3.4 Tailored Properties of Hot Stamping Part 74
3.4.1 Forming Mechanism of Hot Stamping Gradient Strength Steel 75
3.4.2 Experimental Research on District Cooling Process of Gradient Strength Part. 76
3.4.3 Exponential Relation Between Strength-Hardness-Cooling Rate of Hot Stamping Steel 83
3.5 Summary 90
References. 91

4 The Basic Theory and Constitutive Equation of High Strength Steel for Hot Forming 95
4.1 Multifield Coupled Relationship Among Heat, Stress and Phase Transformation. 95
4.1.1 Theoretical Analysis 95
4.1.2 The Determination of the Parameters. 97

4.1.3 The Analysis and Discussion on the Experiment Results. . . . 100
4.1.4 Thermal-Mechanical Transformation Coupled Constitutive Model . . . 102
4.2 Hot Forming Stress and Strain Analysis . . . 104
4.2.1 Mixed Law . . . 104
4.2.2 Strain Analysis . . . 104
4.2.3 Stress Analysis . . . 105
4.3 Constitutive Model of Hot Forming . . . 107
4.3.1 Hot Forming Constitutive Relation of Total Strain Theory . . . 107
4.3.2 Hot Forming Constitutive Relation of Incremental Theory . . . 107
4.4 Summary . . . 108
References . . . 109

5 Constitutive Integration Algorithm of Crystal Thermal Deformation . . . 111
5.1 The Constitutive Integration Method of Single Crystal Finite Deformation at Variable Temperature Conditions . . . 111
5.1.1 Elastic Deformation Gradient as Basic Variable . . . 111
5.1.2 Plastic Deformation Gradient as Basic Variable . . . 114
5.1.3 Stress as the Basic Variable in the Algorithm . . . 116
5.2 Comparison Between Two Deformation Gradient Algorithms . . . 120
5.2.1 Elastic and Plastic Deformation Gradient . . . 120
5.2.2 The Implicit and Explicit Algorithms . . . 121
5.3 The Constitutive Integration Method of Polycrystalline . . . 122
5.3.1 The Construction of Taylor Model . . . 123
5.3.2 The Multiscale Finite Element Model . . . 124
5.4 The Numerical Calculation and Experimental Verification of Thermal Tensile of the High Strength Steel . . . 127
5.4.1 The Thermal–Mechanical Coupling Tensile Experiment . . . 127
5.4.2 Comparison Analysis of the Numerical Simulation . . . 130
5.5 Summary . . . 133
References . . . 133

6 Heat Transfer in Hot Stamping Process of High-Strength Steel . . . 135
6.1 Heat Transfer Theory and Behavior Analysis . . . 135
6.1.1 Basic Principle [1, 2] . . . 135
6.1.2 Heat Transfer Behavior Analysis . . . 137

6.2 Determination of Heat Transfer Coefficient in Hot Stamping Process. . . . 138
6.2.1 Method 138
6.2.2 Determination of Interfacial Heat Transfer Coefficient Between Blank and Tool 139
6.2.3 Determination of Convectional Heat Transfer Coefficient Between Tool and Cooling Water 143
6.3 The Other Factors Influencing the Heat Transfer Coefficient of Hot Stamping Process 150
6.3.1 The Effect of High-Temperature Oxidized Scale 150
6.3.2 The Influence of Heat Transfer Coefficient About Steel Sheet Surface Roughness 160
6.4 Summary 163
References. . . . 163

7 The Formability of High-Strength Steel for Hot Stamping 165
7.1 The Concepts of Plasticity and Deformation Resistance 165
7.2 Factors Influencing Plasticity and Deformation Resistance of Hot Stamping Steel 166
7.2.1 Chemical Composition 166
7.2.2 Metallic Structure 167
7.2.3 Deformation Temperature and Work Hardening 167
7.2.4 Deformation Rate 168
7.2.5 Cooling Rate 170
7.2.6 Deformation Degree 170
7.2.7 Size Factor 171
7.3 Material Properties of High-Strength Steel at Elevated Temperature 171
7.3.1 Uniaxial Tensile Experiment of High-Strength Steel at Elevated Temperature 171
7.3.2 Hardening Model of High-Strength Steel at Elevated Temperature. . . . 173
7.3.3 Effects of Hardening Capacity on Formability. . . . 175
7.3.4 Effects of Directional Anisotropy on Formability 177
7.4 Prediction of Forming Limit for Hot Stamping. . . . 179
7.4.1 Introduction of Forming Limit and Instability Theory. . . . 179
7.4.2 Test Principle of Forming Limit at Elevated Temperature. . . . 182
7.4.3 Test Equipment and Test Procedure of Forming Limit at Elevated Temperature 184
7.4.4 Three-Dimension Thermal Forming Limit Diagram and Its Application 186
7.5 Summary 190
References. . . . 190

8 Hot Stamping Simulation Algorithms of High-Strength Steels 193
8.1 Basic Descriptions of the Hot Stamping Simulation 193
8.2 Several Key Points in Numerical Simulation of Hot Stamping 195
8.2.1 Key technology of Multi-field Coupled Problem 195
8.2.2 Problems of High Temperature Contact Friction 196
8.2.3 The Simulation Technology of Temperature Field. 197
8.2.4 The Simulation Technology of Phase Field 198
8.3 The Model Building and Simulation of Temperature Field in Hot Stamping 199
8.3.1 Summary of Temperature Field FEA in Hot Stamping Process 199
8.3.2 Variational Equation of Temperature Field 203
8.3.3 The Basic Equation of Temperature Shell Elements . . . 207
8.3.4 Discreteness of Space Domain and Time Domain in Shell Transient Temperature Field. 213
8.4 The Modeling and Simulation of Phase Field in Hot Stamping 214
8.4.1 Summary of Phase Field 214
8.4.2 The Basic Equation of Phase Field 215
8.4.3 The Solving Method of Phase Field 217
8.5 Hot Stamping Multi-Field Coupled Numerical Simulation 218
8.5.1 Static Explicit Algorithm for Hot Stamping Multi-Field Coupled Numerical Simulation 218
8.5.2 Dynamic Explicit Finite Element Formulation of Multi-Filed Coupled Hot Stamping Simulation 226
8.6 Summary 240
References. 241

9 Lightweight of Car Body Structure Applied by Hot Stamping Parts 243
9.1 Lightweight of Car Body Structure Applied by Hot Stamping Parts 243
9.1.1 Hot Stamping Door Anti-crash Beam and Its Process Optimization 243
9.1.2 Application of Hot stamping Parts Based on CAE Crash of Whole Vehicle 247
9.1.3 Application of Hot stamping Parts in Concept Body Lightweight Design 251
9.1.4 The Application of Hot stamping Component in Lightweight Design of Large School Bus 260

9.2 The Application of Gradient Hardness Hot stamping Component in Vehicle Bodywork . . . 264
9.2.1 The Research of Crash Energy Absorption Property of Gradient Hardness Hot stamping Component . . . 265
9.2.2 The Application of Gradient Hardness Hot stamping B-Pillar in Vehicle Bodywork and Optimization Design . . . 269
9.3 Summary . . . 275
References . . . 276

10 The Optimization Design and Manufacture of Hot Stamping Mold . . . 279
10.1 The Key Technology of Hot Stamping Mold Design . . . 279
10.1.1 The Whole Structure of Mold . . . 279
10.1.2 The Selection of Material . . . 280
10.1.3 Surface Engineering of Mold . . . 281
10.1.4 Optimization Design of Mold Cooling System . . . 283
10.2 The Optimization of Cooling System in Hot Stamping Dies . . . 284
10.2.1 Optimization of Subsystem Decomposition . . . 284
10.2.2 Virtual Prototype of the Optimization of Mold Cooling . . . 285
10.2.3 Optimizing Core Technology Decomposition . . . 288
10.2.4 Optimization Examples . . . 289
10.3 The Manufacturing of Hot Stamping Mold . . . 292
10.3.1 Mold Heat Treatment . . . 292
10.3.2 Mold Surface Strengthening Treatment . . . 292
10.4 The Thermomechanical Fatigue Test and Life Prediction Simulation of Hot Stamping Die . . . 294
10.4.1 Fatigue Type of Hot Stamping Die . . . 294
10.4.2 Thermomechanical Fatigue Test Device . . . 295
10.4.3 Experimental Principle and Content . . . 295
10.4.4 Experimental Results . . . 297
10.4.5 Life Prediction Simulation . . . 303
10.5 Summary . . . 308
References . . . 308

Index . . . 311



http://www.springer.com/978-981-10-2400-9

Hot Stamping Advanced Manufacturing Technology of Lightweight Car Body

Hu, P.; Ying, L.; He, B.

2017, XVI, 314 p. 218 illus., 134 illus. in color.,
Hardcover
ISBN: 978-981-10-2400-9