METAL FORMING AND THE FINITE-ELEMENT METHOD

SHIRO KOBAYASHI SOO-IK OH TAYLAN ALTAN

New York Oxford
OXFORD UNIVERSITY PRESS
1989

CONTENTS

Symbols, xiii

1. Introduction, 1

- 1.1 Process Modeling, 1
- 1.2 The Finite-Element Method, 3
- 1.3 Solid Formulation and Flow Formulation, 4
- 1.4 Metal Forming and the Finite-Element Method, 5 References, 6

2. Metal-Forming Processes, 8

- 2.1 Introduction, 8
- 2.2 A Metal-Forming Operation as a System, 8
- 2.3 Classification and Description of Metal-Forming Processes, 11 References, 24

3. Analysis and Technology in Metal Forming, 26

- 3.1 Introduction, 26
- 3.2 Flow Stress of Metals, 28
- 3.3 Friction in Metal Forming, 30
- 3.4 Temperatures in Metal Forming, 33
- 3.5 Impression and Closed-Die Forging, 35
- 3.6 Hot Extrusion of Rods and Shapes, 36
- 3.7 Cold Forging and Extrusion, 39
- 3.8 Rolling of Strip, Plate, and Shapes, 41
- 3.9 Drawing of Rod, Wire, Shapes, and Tubes, 45
- 3.10 Sheet-Metal Forming, 47 References, 52

4. Plasticity and Viscoplasticity, 54

- 4.1 Introduction, 54
- 4.2 Stress, Strain, and Strain-Rate, 54
- 4.3 The Yield Criteria, 58
- 4.4 Equilibrium and Virtual Work-Rate Principle, 61

Contents

- 4.5 Plastic Potential and Flow Rule, 63
- 4.6 Strain-Hardening, Effective Stress, and Effective Strain, 66
- 4.7 Extremum Principles, 68
- 4.8 Viscoplasticity, 70 References, 72

5. Methods of Analysis, 73

- 5.1 Introduction, 73
- 5.2 Upper-Bound Method, 74
- 5.3 Hill's General Method, 78
- 5.4 The Finite-Element Method, 83
- 5.5 Concluding Remarks, 88 References, 88

6. The Finite-Element Method—Part I, 90

- 6.1 Introduction, 90
- 6.2 Finite-Element Procedures, 90
- 6.3 Elements and Shape Function, 94
- 6.4 Element Strain-Rate Matrix, 101
- 6.5 Elemental Stiffness Equation, 108 References, 110

7. The Finite-Element Method—Part II, 111

- 7.1 Numerical Integrations, 111
- 7.2 Assemblage and Linear Matrix Solver, 115
- 7.3 Boundary Conditions, 117
- 7.4 Direct Iteration Method, 121
- 7.5 Time-Increment and Geometry Updating, 123
- 7.6 Rezoning, 126
- 7.7 Concluding Remarks, 129 References, 129

8. Plane-Strain Problems, 131

- 8.1 Introduction, 131
- 8.2 Finite-Element Formulation, 131
- 8.3 Closed-Die Forging with Flash, 133
- 8.4 Sheet Rolling, 137
- 8.5 Plate Bending, 141
- 8.6 Side Pressing, 148 References, 149

9. Axisymmetric Isothermal Forging, 151

- 9.1 Introduction, 151
- 9.2 Finite-Element Formulation, 151

Contents ix

- 9.3 Compression of Solid Cylinders and Heading of Cylindrical Bars, 153
- 9.4 Ring Compression, 159
- 9.5 Evaluation of Friction at Tool-Workpiece Interface, 163
- 9.6 Forging and Cabbaging, 165 References, 172

10. Steady-State Processes of Extrusion and Drawing, 174

- 10.1 Introduction, 174
- 10.2 Method of Analysis, 174
- 10.3 Bar Extrusion, 176
- 10.4 Bar Drawing, 178
- 10.5 Multipass Bar Drawing and Extrusion, 183
- 10.6 Applications to Process Design, 186 References, 187

11. Sheet-Metal Forming, 189

- 11.1 Introduction, 189
- 11.2 Plastic Anisotropy, 190
- 11.3 In-plane Deformation Processes, 192
- 11.4 Axisymmetric Out-of-plane Deformation, 195
- 11.5 Axisymmetric Punch-Stretching and Deep-Drawing Processes, 201
- 11.6 Sheet-Metal Forming of General Shapes, 206
- 11.7 Square-Cup Drawing Process, 210
- 11.8 Nonquadratic Yield Criterion, 217 References, 220

12. Thermo-Viscoplastic Analysis, 222

- 12.1 Introduction, 222
- 12.2 Viscoplastic Analysis of Compression of a Solid Cylinder, 223
- 12.3 Heat Transfer Analysis, 225
- 12.4 Computational Procedures for Thermo-Viscoplastic Analysis, 227
- 12.5 Applications, 229
- 12.6 Concluding Remarks, 240 References, 242

13. Compaction and Forging of Porous Metals, 244

- 13.1 Introduction, 244
- 13.2 Yield Criterion and Flow Rules, 245
- 13.3 Finite-Element Modeling and Numerical Procedures, 246
- 13.4 Simple Compression, 249
- 13.5 Axisymmetric Forging of Flange-Hub Shapes, 253

- 13.6 Axisymmetric Forging of Pulley Blank, 256
- 13.7 Heat Transfer in Porous Materials, 259
- 13.8 Hot Pressing Under the Plane-Strain Condition, 262
- 13.9 Compaction, 266 References, 272

x

14. Three-Dimensional Problems, 275

- 14.1 Introduction, 275
- 14.2 Finite-Element Formulation, 276
- 14.3 Block Compressions, 278
- 14.4 Square-Ring Compression, 284
- 14.5 Simplified Three-Dimensional Elements, 287
- 14.6 Analysis of Spread in Rolling and Flat-Tool Forging, 289
- 14.7 Concluding Remarks, 295 References, 296

15. Preform Design in Metal Forming, 298

- 15.1 Introduction, 298
- 15.2 Method for Design, 298
- 15.3 Shell Nosing at Room Temperature, 301
- 15.4 Plane-Strain Rolling, 305
- 15.5 Axially Symmetric Forging, 309
- 15.6 Hot Forming, 315
- 15.7 Concluding Remarks, 318 References, 320

16. Solid Formulation, Comparison of Two Formulations, and Concluding Remarks, 321

- 16.1 Introduction, 321
- 16.2 Small-Strain Solid Formulation, 321
- 16.3 Large Deformation: Rate Form, 323
- 16.4 Large Deformation: Incremental Form, 326
- 16.5 Comparison with Rigid-Plastic (Flow) Solutions, 327
- 16.6 Concluding Remarks, 334 References, 335

Appendix. The FEM Code, SPID (Simple Plastic Incremental Deformation), 338

- A.1 Introduction, 338
- A.2 Program Structure, 339

- A.3 Input and Output Files, 340
 A.4 Input Preparations, 340
 A.5 Description of the Major Variables, 342
 A.6 Program Listing, 343
 A.7 Example Solution, 364

Index, 371