
Contents

Preface	xi
Chapter 1. Forming Processes	1
1.1. Introduction	1
1.2. Different processes	1
1.2.1. Smelting	2
1.2.2. Machining	3
1.2.3. Powder metallurgy	5
1.3. Hot and cold forming	6
1.3.1. Influence of the static parameters	9
1.3.2. Hydroforming	12
1.3.3. The limitations of the process	13
1.3.4. Deep drawing	14
1.4. Experimental characterization	14
1.5. Forming criteria	16
1.5.1. Influence of the structure of sheet metal	18
1.5.2. Physical strain mechanisms	20
1.5.3. Different criteria	21
Chapter 2. Contact and Large Deformation Mechanics	23
2.1. Introduction	23
2.2. Large transformation kinematics	23
2.2.1. Kinematics of the problem in spatial coordinates	24
2.3. Transformation gradient	25
2.4. Strain measurements	26
2.4.1. Polar decomposition of \mathbb{F}	26

2.4.2. Strain rate tensor	27
2.4.3. Canonical decomposition of $\bar{\mathbb{F}}$	28
2.4.4. Kinematics of the problem in convective coordinates	28
2.4.5. Transformation tensor	29
2.4.6. Strain rate measures	32
2.4.7. Strain tensor	35
2.5. Constitutive relations	36
2.5.1. Large elastoplastic transformations	38
2.5.2. Kinematic decomposition of the transformation	41
2.6. Incremental behavioral problem	42
2.6.1. Stress incrementation	42
2.6.2. Strain incrementation	44
2.6.3. Solution of the behavior problem	46
2.7. Definition of the P.V.W. in major transformations	49
2.7.1. Equilibrium equations	49
2.7.2. Definition of the P.V.W.	50
2.7.3. Incremental formulation	51
2.8. Contact kinematics	52
2.8.1. Definition of the problem and notations	52
2.8.2. Contact formulation	53
2.8.3. Formulation of the friction problem	53
2.8.4. Friction laws	54
2.8.5. Coulomb's law	54
2.8.6. Tresca's law	55
Chapter 3. Stamping	57
3.1. Introduction	57
3.2. Forming limit curve	59
3.3. Stamping modeling: incremental problem	60
3.3.1. Modeling of sheet metal	61
3.3.2. Spatial discretization: finite elements method	62
3.3.3. Choice of sheet metal and finite element approximation	63
3.4. Modeling tools	64
3.4.1. Tool surface meshing into simple geometry elements	64
3.4.2. Analytical representation of tools	65
3.4.3. Bezier patches	65
3.5. Stamping numerical processing	72
3.5.1. Problem statement	73
3.5.2. The augmented Lagrangian method	75
3.6. Numerical simulations	79
3.6.1. Sollac test	81

Chapter 4. Hydroforming	83
4.1. Introduction	83
4.2. Hydroforming	85
4.2.1. Tube hydroforming	85
4.2.2. Sheet metal hydroforming	86
4.3. Plastic instabilities in hydroforming	87
4.3.1. Tube buckling	88
4.3.2. Wrinkling	90
4.3.3. Necking	91
4.3.4. Springback	92
4.4. Forming limit curve	92
4.5. Material characterization for hydroforming	94
4.5.1. Tensile testing	95
4.5.2. Bulge testing	95
4.6. Analytical modeling of a inflation test	97
4.6.1. Hill48 criterion in planar stresses	97
4.7. Numerical simulation	100
4.8. Mechanical characteristic of tube behavior	101
Chapter 5. Additive Manufacturing	105
5.1. Introduction	105
5.2. RP and stratoconception	107
5.3. Additive manufacturing definitions	109
5.4. Principle	113
5.4.1. Principle of powder bed laser sintering/melting	114
5.4.2. Principle of laser sintering/melting by projecting powder	116
5.5. Additive manufacturing in the IT-based development process	117
5.5.1. Concept “from the object to the object”	117
5.5.2. Key element of the IT development process	118
Chapter 6. Optimization and Reliability in Forming	121
6.1. Introduction	121
6.2. Different approaches to optimization processes	122
6.2.1. Limitations of the deterministic approaches	124
6.3. Characterization of forming processes by objective functions	125
6.4. Deterministic and probabilistic optimization of a T-shaped tube	126
6.4.1. Problem description	126

6.4.2. Choice of the objective function and definition of the stresses	127
6.4.3. Choice of the uncertain parameters	128
6.4.4. Choice of the objective function and the stresses	130
6.4.5. Deterministic formulation of the optimization problem	132
6.4.6. Probabilistic formulation of the optimization problem	133
6.4.7. Optima sensitivity to uncertainties	140
6.5. Deterministic and optimization-based reliability of a tube with two expansion regions	142
6.5.1. Problem description	142
6.5.2. Deterministic and reliabilist formulation of the optimization problem	147
6.6. Optimization-based reliability of circular sheet metal hydroforming	150
6.6.1. Problem description	150
6.6.2. Construction of the objective function and of the stresses	151
6.6.3. Effects diagram	151
6.6.4. Deterministic solution of the optimization problem	155
6.6.5. Reliabilist solution of the optimization problem	157
6.6.6. Effect of uncertainties on the optimal variables	159
6.7. Deterministic and robust optimization of a square plate	160
6.7.1. Robust resolution of the optimization problem	166
6.8. Optimization of thin sheet metal	168
Chapter 7. Application of Metamodels to Hydroforming	171
7.1. Introduction	171
7.2. Sources of uncertainty in forming	172
7.3. Failure criteria	173
7.3.1. Failure criteria for necking	174
7.3.2. Failure criteria for wrinkling	174
7.4. Evaluation strategy of the probability of failure	175
7.4.1. Finite element model and choice of uncertainty parameters	176
7.4.2. Identification of failure modes and definition of boundary states	180
7.4.3. Identification of elements and critical areas	181
7.5. Critical strains probabilistic characterization	185
7.5.1. Choice of numerical experimental design	186
7.5.2. Construction of metamodels	186
7.5.3. Validation and statistical analysis of metamodels	187

7.5.4. Fitting of distributions	187
7.6. Necking and wrinkling probabilistic study	193
7.7. Effects of the correlations on the probability of failure	196
7.7.1. Spatial estimation of the probability of failures	197
Chapter 8. Parameters Identification in Metal Forming	199
8.1. Introduction	199
8.2. Identification methods	199
8.2.1. Validation test	200
8.3. Welded tube hydroforming	203
8.3.1. Thin sheet metal hydroforming	205
Appendices	213
Appendix 1. Optimization in Mechanics	215
Appendix 2. Reliability in Mechanics	223
Appendix 3. Metamodels	233
Bibliography	243
Index	253