

Contents

1	FE-Models of the Sheet Metal Forming Processes	1
1.1	Introduction	2
1.2	Fundamentals of Continuum Mechanics	3
1.2.1	Introduction	3
1.2.2	Strain Measures	4
1.2.3	Stress Measures	8
1.3	Material Models	9
1.4	FE-Equations for Small Deformations	11
1.5	FE-Equations for Finite Deformations	13
1.6	The ‘Flow Approach’—Eulerian FE-Formulations for Rigid-Plastic Sheet Metal Analysis	16
1.7	The Dynamic, Explicit Method	18
1.8	A Historical Review of Sheet Forming Simulation	21
	References	24
2	Plastic Behaviour of Sheet Metal	27
2.1	Anisotropy of Sheet Metals	30
2.1.1	Uniaxial Anisotropy Coefficients	30
2.1.2	Biaxial Anisotropy Coefficient	36
2.2	Yield Criteria for Isotropic Materials	39
2.2.1	Tresca Yield Criterion	41
2.2.2	Huber–Mises–Hencky Yield Criterion	42
2.2.3	Drucker Yield Criterion	43
2.2.4	Hershey Yield Criterion	44
2.3	Classical Yield Criteria for Anisotropic Materials	45
2.3.1	Hill’s Family Yield Criteria	45
2.3.2	Yield Function Based on Crystal Plasticity (Hershey’s Family)	61
2.3.3	Yield Criteria Expressed in Polar Coordinates	74
2.3.4	Other Yield Criteria	75
2.4	Advanced Anisotropic Yield Criteria	76
2.4.1	Barlat Yield Criteria	77
2.4.2	Banabic–Balan–Comsa (BBC) Yield Criteria	81

2.4.3	Cazacu–Barlat Yield Criteria	84
2.4.4	Vegter Yield Criterion	87
2.4.5	Polynomial Yield Criteria	88
2.5	BBC 2005 Yield Criterion	91
2.5.1	Equation of the Yield Surface	91
2.5.2	Flow Rule Associated to the Yield Surface	92
2.5.3	BBC 2005 Equivalent Stress	92
2.5.4	Identification Procedure	94
2.5.5	Particular Formulations of the BBC 2005 Yield Criterion	105
2.6	BBC 2008 Yield Criterion	106
2.6.1	Equation of the Yield Surface	107
2.6.2	BBC 2008 Equivalent Stress	108
2.6.3	Identification Procedure	109
2.7	Recommendations on the Choice of the Yield Criterion	113
2.7.1	Comparison of the Yield Criteria	113
2.7.2	Evaluating the Performances of the Yield Criteria	116
2.7.3	Mechanical Parameters Used by the Identification Procedure of the Yield Criteria	118
2.7.4	Implementation of the Yield Criteria in Numerical Simulation Programmes	118
2.7.5	Overview of the Anisotropic Yield Criteria Developing	120
2.7.6	Perspectives	120
2.8	Modeling of the Bauschinger Effect	121
2.8.1	Reversal Loading in Sheet Metal Forming Processes	121
2.8.2	Experimental Observations	122
2.8.3	Physical Nature of the Bauschinger Effect	124
2.8.4	Phenomenological Modelling	125
	References	135
3	Formability of Sheet Metals	141
3.1	Introduction	142
3.2	Evaluation of the Sheet Metal Formability	147
3.2.1	Methods Based on Simulating Tests	147
3.2.2	Limit Dome Height Method	151
3.3	Forming Limit Diagram	152
3.3.1	Definition: History	152
3.3.2	Experimental Determination of the FLD	156
3.3.3	Methods of Determining the Limit Strains	162
3.3.4	Factors Influencing the FLC	165
3.3.5	Use of Forming Limit Diagrams in Industrial Practice	175
3.4	Theoretical Predictions of the Forming Limit Curves	179
3.4.1	Swift's Model	180
3.4.2	Hill's Model	182
3.4.3	Marciniak–Kuczynski (M–K) and Hutchinson–Neale (H–N) Models	182

3.4.4	Implicit Formulation of the M–K and H–N Models	185
3.4.5	Linear Perturbation Theory	194
3.4.6	Modified Maximum Force Criterion (MMFC)	195
3.5	Commercial Programs for FLC Prediction	197
3.5.1	FORM-CERT Program	198
3.6	Semi-empirical Models	203
	References	204
4	Numerical Simulation of the Sheet Metal Forming Processes	213
4.1	AutoForm Solutions	213
4.1.1	The Role of Simulation in Process Planning	213
4.1.2	Material Data in Digital Process Planning	215
4.1.3	Feasibility (Part Feasibility)	218
4.1.4	Manufacturability (Process Validation)	225
4.1.5	Capability (Robustness)	230
4.1.6	Simulation Result ‘Quality’	236
4.1.7	Comprehensive Digital Process Planning	236
4.2	Simulation of the Elementary Forming Processes	238
4.2.1	Simulation of the Bulge Forming Process	238
4.2.2	Simulation of Stretch Forming of Spherical Cup	241
4.2.3	Simulation of Cross Die	244
4.3	Simulation of the Industrial Parts Forming Processes	250
4.3.1	Simulation of an Outer Trunklid	251
4.3.2	Simulation of a Sill Reinforcement for Volvo C30	254
4.4	Robust Design of Sheet Metal Forming Processes	255
4.4.1	Variability of the Material Parameters	256
4.4.2	AutoForm-Sigma	257
4.4.3	Robust Design: Case Studies	258
4.4.4	Conclusion	267
4.5	The Springback Analysis	267
4.5.1	Introduction	267
4.5.2	Example Description	268
4.5.3	The Influences on the Accuracy of Springback Simulation	269
4.5.4	The Optimized Numerical Parameters of Springback Simulation: Final Validation Settings	277
4.5.5	The Simulation of Numisheet 2005 Benchmark #1: Decklid Inner Panel	277
4.5.6	Conclusion	281
4.6	Computer Aided Springback Compensation	282
4.6.1	Introduction	282
4.6.2	The Basic Methodologies of Computer-Aided Springback Compensation	283
4.6.3	The Influences of the Quality of Computer Aided Springback Compensation	284

4.6.4	The Recommended Work Flow of Computer-Aided Springback Compensation	285
4.6.5	The Springback Compensation of Numisheet 2005 Benchmark #1	287
4.6.6	Conclusion	293
	References	294
	Index	297