

Contents

Preface	V
About the Author	VII
List of Symbols Used in the Book	IX
1 Introduction	1
1.1 References	2
2 Phenomenological Evidence of Elasticity	3
2.1 Effects Due to Normal Stresses	3
2.2 Extrudate Swell	4
2.3 Contraction Flow	4
2.4 Time Dependence	5
2.5 References	6
3 Principles of the Determination of Elastic Properties	7
3.1 Creep Recovery Experiment and Retardation Spectrum	7
3.2 Relaxation Experiment and Relaxation Spectrum	11
3.3 Dynamic-Mechanical Experiment	12
3.4 Stressing Experiment	15
3.5 Capillary Rheometry	16
3.6 Recoverable Elongation	18
3.7 References	19

4	Experimental Basics of Various Methods for Measuring the Elastic Behavior	21
4.1	Thermal Stability	21
4.2	Linearity and Stationarity	23
4.2.1	Creep Recovery Experiment	23
4.2.2	Relaxation Experiment	27
4.2.3	Dynamic-Mechanical Experiments	27
4.2.4	Stressing Experiments	28
4.2.5	Extrudate Swell	29
4.2.6	Recoverable Elongation	31
4.3	References	34
5	Dependence of Elastic Quantities on Experimental Parameters	37
5.1	Recoverable Compliance	37
5.1.1	Stress Dependence	37
5.1.2	Temperature Dependence	38
5.2	Relaxation Modulus	41
5.3	Storage Modulus	44
5.4	Normal Stress Difference	45
5.5	Recoverable Elongation	48
5.6	Extrudate Swell	50
5.6.1	General Features of Extrudate Swell	50
5.6.2	Detailed Analysis of Extrudate Swell	52
5.6.3	Extrudate Swell for Various Die Geometries	53
5.7	References	54
6	Dependence of Elastic Properties on Molecular Structure	57
6.1	Analysis of Molecular Structure	57
6.1.1	Molar Mass Distribution and Its Characteristic Quantities	57
6.1.2	Branches and Their Analysis	60
6.2	Influence of Molar Mass	64
6.2.1	Linear Elastic Properties	64
6.2.2	Nonlinear Elastic Properties	66
6.3	Influence of Molar Mass Distribution	68
6.3.1	Linear Elastic Properties	68
6.3.1.1	Dependence on the Polydispersity Index	69
6.3.1.2	Effect of High Molar Mass Components	73
6.3.2	Nonlinear Elastic Properties	77

6.4	Influence of Long-Chain Branching	83
6.4.1	Linear Elastic Properties	83
6.4.1.1	Long-Chain Branched Polystyrenes	83
6.4.1.2	Long-Chain Branched Polyolefins	84
6.4.1.3	Temperature Dependence of Linear Elastic Compliances	86
6.4.1.4	Retardation Spectra	88
6.4.1.5	Relaxation Spectra	92
6.4.2	Nonlinear Elastic Properties	94
6.4.2.1	Recoverable Compliance	94
6.4.2.2	Damping Function	95
6.4.2.3	Extrudate Swell	96
6.4.2.4	Recoverable Elongation	99
6.5	Influence of Mechanical Pretreatments on Elastic Properties	101
6.5.1	Extrudate Swell of Long-Chain Branched Polyethylenes	101
6.5.2	Elastic Properties of a Long-Chain Branched and a Linear Polypropylene	104
6.6	References	106
7	Models for the Description of Elastic Effects	111
7.1	Spring-Dashpot Models	111
7.2	Entanglements	114
7.3	Doi-Edwards Theory	116
7.4	Theory for Long-Chain Branched Polymers	117
7.5	Mixing Rule for the Linear Steady-State Recoverable Compliance of Blends	119
7.6	Numerical Description of the Nonlinear Behavior of the Steady-State Recoverable Compliance	123
7.7	Numerical Descriptions of Extrudate Swell	125
7.7.1	Entry Region	125
7.7.2	Flow within the Capillary	126
7.8	References	128
8	Elastic Behavior and Its Relevance for Various Applications ..	131
8.1	Creep Recovery Experiments as a Contribution to Molecular Analysis ..	131
8.1.1	Creep Recovery Compliance	131
8.1.2	Retardation Spectra	133
8.1.3	Calculation of Dynamic-Mechanical Quantities from Retardation Spectra	135
8.2	Elastic Properties and Entrance Flow Patterns	137

8.3	Elastic Behavior of Refined Polyethylenes and Their Relation to End-Use Properties	140
8.3.1	Application-Related Properties of IUPAC C in Comparison with IUPAC A	141
8.3.2	Optical Properties of Various Polyethylenes After Mechanical Pretreatments	141
8.4	Extrudate Swell as a Quantity for Qualitative Material Specifications ..	142
8.5	References	144
9	Polymeric Materials with Microparticles	147
9.1	General Experimental Features	147
9.1.1	Slip and Edge Fracture	147
9.1.2	Yielding	148
9.2	Glass Beads as Fillers	150
9.2.1	Determination of Yield Stresses	150
9.2.2	Recoverable Strain	153
9.2.3	Colloidal Glasses	155
9.2.4	Model for Suspended Glass Beads of Microsize	155
9.2.5	Dynamic-Mechanical Measurements	157
9.3	Normal Stress Differences and Recoverable Strain	159
9.4	Extrudate Swell	163
9.5	Various Microfillers	165
9.6	References	165
10	Polymeric Materials with Nanoparticles	167
10.1	Nanoparticles Investigated	168
10.2	Dynamic-Mechanical Experiments	171
10.2.1	Determination of Linear Behavior	171
10.2.2	Melts with Various Concentrations of Nanoparticles	172
10.3	Creep and Creep Recovery Experiments	176
10.3.1	Influence of a Particle Network	176
10.3.2	Nanosilica-Filled PMMA as a Model System	177
10.3.3	Retardation Spectra	179
10.4	Model	180
10.4.1	Experimental Results Supporting the Model	182
10.4.1.1	Dependence of the Recoverable Compliance on Filler Size	182
10.4.1.2	Stress Dependence of the Recoverable Compliance	182

10.5	Temperature Dependence of Creep and Creep Recovery	185
10.6	Influence of the Polymer Matrix on the Linear Steady-State Recoverable Compliance	188
10.7	Linear Elastic Properties of Melts with Various Nanofillers	190
10.7.1	Polymethylmethacrylate with Nanoclay	191
10.7.2	Polymethylmethacrylate with Graphite	192
10.7.3	Polymethylmethacrylate, Polycarbonate, and Polypropylene with Carbon Nanotubes	193
10.8	Nonlinear Elastic Properties	195
10.8.1	Extrudate Swell	195
10.8.2	Recoverable Elongation	196
10.9	Comparison of Nonlinear and Linear Elastic Properties	198
10.10	References	198
11	Immiscible Polymer Blends	201
11.1	Linear Elastic Behavior	202
11.1.1	Dynamic-Mechanical Experiments	202
11.1.2	Recoverable Shear	208
11.2	Nonlinear Elastic Behavior	211
11.2.1	Recoverable Elongation	212
11.2.2	Extrudate Swell	215
11.3	References	217
12	Influence of Elastic Properties on Processing	219
12.1	Measurement of Elastic Quantities at High Shear Rates	219
12.2	The Role of Extrudate Swell in the Shape of Extruded Parts	222
12.3	The Role of Extrudate Swell in Pelletizing	223
12.4	The Role of Extrudate Swell in Additive Manufacturing by Material Extrusion	224
12.5	Extrudate Swell and Extrusion through an Annular Die	225
12.6	Extrudate Swell of Rectangular Dies	228
12.7	Influence of Tensile Stress on Extrudate Swell	231
12.8	Elastic Properties of Polymer Melts and Their Relation with Film Drawing	233
12.8.1	Basic Features of Film Drawing	233
12.8.2	Models for the Drawing Process	234
12.8.3	Drawing Experiments on Three Polypropylenes	236

12.9 Draw Resonance	238
12.9.1 Film Drawing	238
12.9.2 Fiber Spinning	242
12.9.3 Comparison with Results from the Literature	243
12.10 References	244
13 Influences of Processing on Molecular Orientation and Recoverable Strain	247
13.1 General Influence of Processing	247
13.2 Molecular Orientation and Recoverable Strain	249
13.3 Injection-Molded Parts from Amorphous Polymers	252
13.3.1 Recoverable Strain within an Injection-Molded Part	252
13.3.2 Mechanical Properties of Injection-Molded Parts	254
13.4 Films from Semi-crystalline Polymers	257
13.4.1 Stretch Films	258
13.4.2 Shrink Films	261
13.4.2.1 Thermal Shrinkage of Uniaxially Stretched Films	262
13.4.2.2 Shrinkage of Biaxially Stretched Films	263
13.4.3 Role of Molecular Orientation for Applications	265
13.4.3.1 Applications of Stretch Films	265
13.4.3.2 Applications of Shrink Films	266
13.5 References	267
Index	269