

Contents

Preface	V
About the Author	VII
1 Mechanical Properties of Solid Polymers	1
1.1 Ideal Solids	1
1.2 Tensile Properties	2
1.2.1 Stress-Strain Behavior	3
1.2.2 Tensile Modulus	5
1.2.3 Effect of Temperature on Tensile Strength	7
1.3 Shear Properties	7
1.3.1 Shear Modulus	8
1.3.2 Effect of Temperature on Shear Modulus	8
1.4 Compressive Properties	10
1.4.1 Bulk Modulus	11
1.5 Time Related Properties	12
1.5.1 Creep Modulus	12
1.5.2 Creep Rupture	14
1.5.3 Relaxation Modulus	14
1.5.4 Fatigue Limit	15
1.6 Hardness	18
1.7 Impact Strength	19
1.8 Coefficient of Friction	19
1.9 References	24
2 Thermal Properties of Solid and Molten Polymers	25
2.1 Specific Volume	25
2.2 Specific Heat	28

2.3	Thermal Expansion Coefficient	30
2.4	Enthalpy	31
2.5	Thermal Conductivity	32
2.6	Thermal Diffusivity	33
2.7	Coefficient of Heat Penetration	35
2.8	Heat Deflection Temperature	36
2.9	Vicat Softening Point	37
2.10	Flammability	38
2.11	References	41
3	Transport Properties of Molten Polymers	43
3.1	Newtonian and Non-Newtonian Fluids	43
3.2	Viscous Shear Flow	45
3.2.1	Apparent Shear Rate	45
3.2.2	Entrance Loss	46
3.2.3	True Shear Stress	47
3.2.4	Apparent Viscosity	48
3.2.5	True Shear Rate	50
3.2.6	True Viscosity	51
3.3	Rheological Models	51
3.3.1	Hyperbolic Function of Eyring and Prandtl	51
3.3.2	Power Law of Ostwald and de Waele	52
3.3.3	Polynomial of Münstedt	54
3.3.3.1	Shift Factor for Crystalline Polymers	55
3.3.3.2	Shift Factor for Amorphous Polymers	55
3.3.4	Viscosity Equation of Carreau	57
3.3.5	Viscosity Formula of Klein	60
3.4	Effect of Pressure on Viscosity	61
3.5	Dependence of Viscosity on Molecular Weight	62
3.6	Viscosity of Two-Component Mixtures	63
3.7	Melt Flow Index	63
3.8	Tensile Viscosity	65
3.9	Viscoelastic Properties	65
3.9.1	Primary Normal Stress Coefficient, Q	65
3.9.2	Shear Compliance, J_e	66
3.9.3	Die Swell	67
3.10	Rheology of Glass Fiber-Filled Polypropylene Melts	67

3.10.1	Introduction	67
3.10.2	Model	68
3.10.3	Shift Factor as a Function of Fiber Content	70
3.10.4	Example	71
3.10.5	Summary	73
3.11	Practical Computational Rheology Primer	73
3.11.1	Introduction	73
3.11.2	Shear Flow	75
3.11.2.1	Relationship between Flow Rate and Pressure Drop	75
3.11.2.2	Shear Rates for Blown Film and Extrusion Coating Dies	78
3.11.2.3	Extensional Flow	80
3.11.2.4	Melt Elasticity	80
3.12	Conclusions	84
3.13	References	84
4	Electrical Properties	87
4.1	Surface Resistivity	87
4.2	Volume Resistivity	87
4.3	Dielectric Strength	88
4.4	Relative Permittivity	88
4.5	Dielectric Dissipation Factor or Loss Tangent	89
4.6	Comparative Tracking Index (CTI)	90
4.7	References	92
5	Optical Properties of Solid Polymers	93
5.1	Light Transmission	93
5.2	Haze	93
5.3	Refractive Index	94
5.4	Gloss	95
5.5	Color	95
5.6	References	96
6	External Influences	97
6.1	Physical Interactions	97
6.1.1	Solubility	97
6.1.2	Environmental Stress Cracking (ESC)	97

6.1.3	Permeability	99
6.1.4	Absorption and Desorption	100
6.1.5	Weathering Resistance	100
6.2	Chemical Resistance	101
6.2.1	Chemical and Wear Resistance to Polymers	102
6.3	General Property Data	103
6.4	References	110
7	Extrusion	111
7.1	Extrusion Screws	112
7.2	Processing Parameters	114
7.2.1	Resin-Dependent Parameters	114
7.2.1.1	Blown Film	115
7.2.1.2	Pipe Extrusion	116
7.2.1.3	Flat Film Extrusion	117
7.2.1.4	Sheet Extrusion	117
7.2.1.5	Wire Coating	118
7.2.2	Machine-Related Parameters	118
7.2.2.1	Extruder Output	118
7.2.2.1.1	Feed Zone	118
7.2.2.1.2	Metering Zone (Melt Zone)	120
7.2.2.2	Melting Parameter	127
7.2.2.3	Melting Profile	129
7.2.2.4	Screw Power	130
7.2.2.5	Melt Temperature and Melt Pressure	132
7.2.2.5.1	Melt Temperature	132
7.2.2.5.2	Temperature Fluctuation	133
7.2.2.5.3	Melt Pressure	134
7.2.2.5.4	Pressure Fluctuation	134
7.3	Extrusion Dies	145
7.3.1	Pipe Extrusion	147
7.3.1.1	General Cross Section	149
7.3.1.2	Drawdown and Haul-Off Rates	153
7.3.2	Blown Film	155
7.3.3	Sheet Extrusion	161
7.4	Thermoforming	163
7.5	Compounding	167
7.5.1	Coextrusion	168

7.6	Extrudate Cooling	170
7.6.1	Dimensionless Groups	173
7.7	References	175
8	Blow Molding	177
8.1	Processes	177
8.1.1	Resin-Dependent Parameters	179
8.1.1.1	Melt Temperature and Pressure	179
8.1.1.1.1	Processing Data for Stretch Blow Molding	180
8.1.1.1.2	Volume Shrinkage	180
8.1.1.1.3	Choice of Material	181
8.1.2	Machine-Related Parameters	181
8.1.2.1	Blow Molding Dies	181
8.2	References	183
9	Injection Molding	185
9.1	Resin-Dependent Parameters	188
9.1.1	Injection Pressure	188
9.1.2	Mold Shrinkage and Processing Temperature	188
9.1.3	Drying Temperatures and Times	191
9.1.4	Flow Characteristics of Injection-Molding Resins	191
9.2	Machine-Related Parameters	196
9.2.1	Injection Unit	196
9.2.2	Injection Molding Screw	197
9.2.2.1	Nonreturn Valves	198
9.2.2.1.1	Nozzle	199
9.2.3	Injection Mold	200
9.2.3.1	Runner Systems	200
9.2.3.2	Design of Gates	202
9.2.3.3	Injection Pressure and Clamp Force	204
9.2.4	Mechanical Design of Mold	212
9.3	Melting in Injection Molding Screws	214
9.3.1	Model	214
9.3.2	Calculation Procedure	216
9.3.3	Sample Calculation	216
9.3.4	Results of Simulation	217
9.3.5	Screw Dimensions	219

9.4 Injection Mold 220

9.4.1 Runner Systems 220

9.4.2 Calculated Example 220

9.4.3 Mold Filling 222

9.4.4 Injection Pressure 222

9.4.5 Calculated Example with Symbols and Units 223

9.5 Flow Characteristics of Injection Molding Resins 225

9.5.1 Model 226

9.5.2 Melt Viscosity and Power Law Exponent 227

9.5.3 Experimental Results and Discussion 228

9.5.4 Sample Calculation 230

9.6 Cooling of Melt in the Mold 231

9.6.1 Crystalline Polymers 231

9.6.2 Amorphous Polymers 233

9.6.3 Calculations with Varying Mold Wall Temperature 234

9.6.3.1 Sample Calculation with Symbols and Units 235

9.6.3.2 Iteration Procedure 236

9.6.3.3 Results of Calculations with the Model 236

9.7 Rheological Design of the Mold 240

9.7.1 Sample Calculation 240

9.7.2 General Channel Shape 243

9.8 References 243

9.9 Appendix 245

Index 247