

# **International Plastics Handbook**

Sigrid Brinkmann, Karl Oberbach, Erwin  
Baur, Ernst Schmachtenberg, Tim A.  
Osswald

The Resource for Plastics Engineers

ISBN 3-446-22905-1

Weitere Informationen oder Bestellungen unter  
<http://www.hanser.de/3-446-22905-1> sowie im Buchhandel

# CONTENTS

---

Preface	vii
<b>1 Introduction</b>	<b>1</b>
1.1 Statistical data	1
1.2 Polymer and plastics categories	5
1.3 Plastics Acronyms	8
<b>2 Materials Science of Polymers</b>	<b>17</b>
2.1 Polymer Structure	17
2.1.1 Chemistry	17
2.1.2 Morphological Structure	35
2.1.3 Thermal Transitions	39
2.2 Material Modification of Plastics	53
2.2.1 Polymer Blends	53

---

2.2.2 Filled Polymers and Reinforced Composites	54
2.2.3 Other Modifications	57
2.3 Plastics Recycling	58
<b>3 Properties and Testing</b>	<b>63</b>
3.1 Comparability of Material Properties	63
3.2 Thermal Properties	67
3.2.1 Thermal Conductivity	67
3.2.2 Specific Heat and Specific Enthalpy	74
3.2.3 Density	76
3.2.4 Thermal Diffusivity	82
3.2.5 Linear Coefficient of Thermal Expansion	82
3.2.6 Thermal Penetration	91
3.2.7 Thermal Data Measuring Devices	92
3.3 Curing Behavior	99
3.4 Rheological Properties	103
3.4.1 Flow Phenomena	103
3.4.2 Viscous Flow Models	109
3.4.3 Rheometry	115
3.4.4 Surface Tension	122
3.5 Mechanical Properties	126
3.5.1 The Short-Term Tensile Test	126
3.5.2 Impact Strength	141
3.5.3 Creep Behavior	160
3.5.4 Dynamic Mechanical Tests	172
3.5.5 Fatigue Tests	178
3.5.6 Strength Stability Under Heat	185
3.6 Permeability properties	194
3.6.1 Sorption	195
3.6.2 Diffusion and Permeation	195
3.6.3 Measuring $S$ , $D$ , and $P$	201
3.6.4 Diffusion of Polymer Molecules and Self-Diffusion	203
3.7 Friction and Wear	205
3.8 Environmental effects	207
3.8.1 Water Absorption	208

---

3.8.2	Weathering	211
3.8.3	Chemical Degradation	214
3.8.4	Thermal Degradation of Polymers	216
3.9	Electrical Properties	223
3.9.1	Dielectric Behavior	223
3.9.2	Electric Conductivity	229
3.9.3	Application Problems	235
3.9.4	Magnetic Properties	247
3.10	Optical Properties	249
3.10.1	Index of Refraction	250
3.10.2	Photoelasticity and Birefringence	251
3.10.3	Transparency, Reflection, Absorption and Transmittance	257
3.10.4	Gloss	259
3.10.5	Color	262
3.10.6	Infrared Spectroscopy	263
3.11	Acoustic Properties	266
3.11.1	Speed of Sound	266
3.11.2	Sound Reflection	266
3.11.3	Sound Absorption	268
<b>4</b>	<b>Plastics Processes</b>	<b>271</b>
4.1	Raw Material Preparation	272
4.1.1	Mixing Processes	272
4.2	Mixing Devices	275
4.2.1	Mixing of Particulate Solids	275
4.2.2	Screw-Type Mixers	275
4.2.3	Granulators and Pelletizers	288
4.2.4	Dryers	290
4.3	Extrusion	294
4.3.1	The Plasticating Extruder	296
4.3.2	Troubleshooting Extrusion	304
4.3.3	Extrusion Dies	308
4.4	Injection Molding	314
4.4.1	The Injection Molding Cycle	314
4.4.2	The Injection Molding Machine	318

---

4.4.3 Special Injection Molding Processes	325
4.4.4 Troubleshooting Injection Molding	368
4.5 Compression Molding	369
4.5.1 Compression Molding of SMC and BMC	371
4.5.2 Compression Molding of GMT and LFT	373
4.5.3 Cold Press Forming	376
4.5.4 Troubleshooting Compression Molding	377
4.6 Composites Processing	381
4.6.1 Resin Transfer Molding and Structural RIM	382
4.6.2 Filament Winding	384
4.6.3 Pultrusion	385
4.7 Secondary Shaping	386
4.7.1 Fiber Spinning	387
4.7.2 Film Production	388
4.7.3 Thermoforming	397
4.8 Calendering	400
4.9 Coating	402
4.10 Foaming	407
4.11 Rotational Molding	410
4.12 Welding	412
4.12.1 Hot Tool Butt Welding	413
4.12.2 Ultrasonic Welding	416
4.12.3 Vibration Welding	424
4.12.4 Spin Welding	427
4.12.5 IR and Laser Welding	430
4.12.6 RF/Dielectric Welding	433
4.12.7 Hot Gas Welding	435
4.12.8 Extrusion Welding	437
4.12.9 Implant Induction Welding	439
4.12.10 Implant Resistance Welding	442
4.12.11 Microvawe Welding	444
4.13 Rapid Prototyping	444
4.13.1 Stereo-Lithography (STL)	445
4.13.2 Solid Ground Curing (SGC)	445
4.13.3 Selective Laser Sintering (SLS)	446

---

4.13.4	3D Printing or Selective Binding	447
4.13.5	Fused Deposition Modeling (FDM)	448
4.13.6	Laminated Object Manufacturing (LOM)	449
<b>5</b>	<b>Engineering Design</b>	<b>451</b>
5.1	Design Philosophy	451
5.1.1	Defining Product Requirements	453
5.1.2	Preliminary CAD Model	454
5.1.3	Material Selection	455
5.1.4	Process Selection	458
5.2	Process Influences on Product Performance	458
5.2.1	Orientation in the Final Part	459
5.2.2	Fiber Damage	465
5.2.3	Cooling and Solidification	467
5.2.4	Shrinkage, Residual Stresses and Warpage	470
5.2.5	Process Simulation as Integral Part of the Design Process	476
5.3	Strength of Materials Considerations	485
5.3.1	Basic Concepts of Stress and Strain	485
5.3.2	Anisotropic Strain-Stress Relation	494
5.4	Functional Elements	498
5.4.1	Press Fit Assemblies	498
5.4.2	Living Hinges	499
5.4.3	Snap Fit Assemblies	499
5.4.4	Mechanical Fasteners	504
5.5	Software	505
<b>6</b>	<b>Materials</b>	<b>507</b>
6.1	Polyolefins (PO), Polyolefin Derivates, and Copolymers	508
6.1.1	Standard Polyethylene Homo- and Copolymers (PE-LD, PE-HD, PE-HD-HMW, PE-HD-UHMW, PE-LLD)	513
6.1.2	Polyethylene Derivates (PE-X, PE + PSAC)	523
6.1.3	Chlorinated and Chloro-Sulfonated PE (PE-C, CSM)	524
6.1.4	Ethylene Copolymers (ULDPE, EVAC, EVAL, EEAk, EB, EBA, EMA, EAA, E/P, EIM, COC, ECB, ETFE)	525
6.1.5	Polypropylene Homopolymers (PP, H-PP)	533

6.1.6 Polypropylene Copolymers and -Derivates, Blends (PP-C, PP-B, EPDM, PP + EPDM)	539
6.1.7 Polypropylene, Special Grades	541
6.1.8 Polybutene (PB, PIB)	542
6.1.9 Higher Poly- $\alpha$ -Olefins (PMP, PDCPD)	545
6.2 Styrene Polymers	546
6.2.1 Polystyrene, Homopolymers (PS, PMS)	546
6.2.2 Polystyrene, Copolymers, Blends	547
6.2.3 Polystyrene Foams (PS-E, XPS)	553
6.3 Vinyl Polymers	554
6.3.1 Rigid Polyvinylchloride Homopolymers (PVC-U)	554
6.3.2 Plasticized (soft) Polyvinylchloride (PVC-P)	560
6.3.3 Polyvinylchloride: Copolymers and Blends	565
6.3.4 Polyvinylchloride: Pastes, Plastisols, Organosols	566
6.3.5 Vinyl Polymers, other Homo- and Copolymers (PVDC, PVAC, PVAL, PVME, PVB, PVK, PVP)	567
6.4 Fluoropolymers	569
6.4.1 Fluoro Homopolymers (PTFE, PVDF, PVF, PCTFE)	569
6.4.2 Fluoro Copolymers and Elastomers (ECTFE, ETFE, FEP, TFEP, PFA, PTFEAF, TFEHFPVDF (THV), [FKM, FPM, FFKM])	574
6.5 Polyacryl- and Methacryl Copolymers	576
6.5.1 Polyacrylate, Homo- and Copolymers (PAA, PAN, PMA, ANBA, ANMA)	576
6.5.2 Polymethacrylates, Homo- and Copolymers (PMMA, AMMA, MABS, MBS)	577
6.5.3 Polymethacrylate, Modifications and Blends (PMMI, PMMA-HI, MMA-EML Copolymers, PMMA + ABS blends)	581
6.6 Polyoxymethylene, Polyacetal Resins, Polyformaldehyde (POM)	584
6.6.1 Polyoxymethylene Homo- and Copolymers (POM-H, POM-Cop.)	584
6.6.2 Polyoxymethylene, Modifications and Blends (POM + PUR)	585
6.7 Polyamides (PA)	586
6.7.1 Polyamide Homopolymers (AB and AA/BB Polymers) (PA6, 11, 12, 46, 66, 69, 610, 612, PA 7, 8, 9, 1313, 613)	586

6.7.2	Modifications	593
6.7.3	Polyamide Copolymers, PA 66/6, PA 6/12, PA 66/6/610 Blends (PA +: ABS, EPDM, EVA, PPS, PPE, Rubber)	594
6.7.4	Polyamides, Special Polymers (PA NDT/INDT [PA 6-3-t], PAPACM 12, PA 6-I, PA MXD6 [PARA], PA 6-T, PA PDA-T, PA 6-6-T, PA 6-G, PA 12-G, TPA-EE)	597
6.7.5	Cast Polyamides (PA 6-C, PA 12-C).	598
6.7.6	Polyamide for Reaction Injection Molding (PA-RIM)	598
6.7.7	Aromatic Polyamides, Aramides (PMPI, PPTA)	599
6.8	Aromatic (Saturated) Polyesters	599
6.8.1	Polycarbonate (PC)	600
6.8.2	Polyesters of Therephthalic Acids, Blends, Block Copolymers	605
6.8.3	Polyesters of Aromatic Diols and Carboxylic Acids (PAR, PBN, PEN)	610
6.9	Aromatic Polysulfides and Polysulfones (PPS, PSU, PES, PPSU, PSU + ABS)	613
6.9.1	Polyphenylene Sulfide (PPS)	613
6.9.2	Polyarylsulfone (PSU, PSU + ABS, PES, PPSU)	616
6.10	Aromatic Polyether, Polyphenylene Ether, and Blends (PPE)	617
6.10.1	Polyphenylene Ether (PPE)	617
6.10.2	Polyphenylene Ether Blends	618
6.11	Aliphatic Polyester (Polyglycols) (PEOX, PPOX, PTHF)	620
6.12	Aromatic Polyimide (PI)	622
6.12.1	Thermosetting Polyimide (PI, PBMI, PBI, PBO, and Others)	623
6.12.2	Thermoplastic Polyimides (PAI, PEI, PISO, PMI, PMMI, PESI, PARI)	627
6.13	Liquid Crystalline Polymers (LCP)	629
6.14	Ladder Polymers: Two-Dimensional Polyaromates and - Heterocyclenes	632
6.15	Polyurethane (PUR)	635
6.15.1	Fundamentals	635
6.15.2	Raw Materials and Additives	639
6.15.3	PUR Polymers	642
6.16	Biopolymers, Naturally Occurring Polymers and Derivates	650



6.16.1 Cellulose- and Starch Derivates (CA, CTA, CAP, CAB, CN, EC, MC, CMC, CH, VF, PSAC)	650
6.16.2 Casein Polymers, Casein Formaldehyde, Artificial Horn (CS, CSF)	656
6.16.3 Polylactide, Polylactic Acid (PLA)	656
6.16.4 Polytriglyceride Resins (PTP®)	656
6.16.5 Natural Resins	657
6.17 Other Polymers	657
6.17.1 Photodegradable, Biodegradable, and Water Soluble Polymers	657
6.17.2 Conductive/Luminescent Polymers	659
6.17.3 Aliphatic Polyketones (PK)	662
6.17.4 Polymer Ceramics, Polysilicooxoaluminate (PSIOA)	664
6.18 Thermoplastic Elastomers (TPE)	664
6.18.1 Physical Constitution	666
6.18.2 Chemical Constitution, Properties, and Applications	666
6.19 Thermosets	670
6.19.1 Chemical Constitution	670
6.19.2 Processing, Forms of Delivery	676
6.19.3 Properties	678
6.19.4 Applications	683
6.20 Rubbers	686
6.20.1 General Description	686
6.20.2 General Properties	687
6.20.3 R-Rubbers (NR, IR, BR, CR, SBR, NBR, NCR, IIR, PNR, SIR, TOR, HNBR)	689
6.20.4 M-Rubbers (EPM, EPDM, AECM, EAM, CSM, CM, ACM, ABM, ANM, FKM, FPM, FFKM)	693
6.20.5 O-Rubbers (CO, ECO, ETER, PO)	695
6.20.6 Q-(Silicone) Rubber (MQ, MPQ, MVQ, PVMQ, MFQ, MVFQ)	696
6.20.7 T-Rubber (TM, ET, TCF)	697
6.20.8 U-Rubbers (AFMU, EU, AU)	698
6.20.9 Polyphosphazenes (PNF, FZ, PZ)	699
6.20.10 Other Rubbers	699

---

<b>7 Polymer Additives</b>	<b>701</b>
7.1 Antiblocking Agents	701
7.2 Slip Additives	702
7.3 Plasticizers	702
7.4 Stabilizers	702
7.4.1 Antioxidants	703
7.4.2 Flame Retardants	704
7.4.3 UV Stabilizers	705
7.4.4 PVC Stabilizers	706
7.5 Antistatic Agents	706
7.6 Antimicrobial Agents	707
7.7 Antifogging Agents	708
7.8 Blowing Agents	709
7.9 Colorants	710
7.10 Fluorescent Whitening Agents	712
7.11 Fillers	712
<b>Appendix A: Material Property Tables</b>	<b>717</b>
<b>Appendix B: Literature</b>	<b>775</b>
B.1 Books in the Plastics Technology Field	776
B.2 Journals and Trade Magazines	788
B.2.1 Trade Magazines	788
B.2.2 Archival Journals	789
<b>Appendix C: Polymer Research Institutes</b>	<b>791</b>
<b>Appendix D: Tradenames</b>	<b>805</b>
D.1 Introduction	806
D.2 Tradenames Table	807
Topic Index	877