

HANSER

Designing with Plastics

Gunter Erhard

ISBN 3-446-22590-0

Inhaltsverzeichnis

Weitere Informationen oder Bestellungen unter
<http://www.hanser.de/3-446-22590-0> sowie im Buchhandel

Contents

1	Market Overview	1
1.1	Examples of Applications from Various Industry Sectors	4
1.1.1	Aerospace	4
1.1.2	Precision Engineering	7
1.1.3	Automotive Engineering	9
1.1.4	General Mechanical Engineering	14
1.1.5	Design of Technical Equipment	15
1.1.6	Construction Industry	18
1.2	Forecast	22
2	Structure and Properties	31
2.1	Chemical Structure (Constitution)	31
2.1.1	Degree of Polymerization – Relative Molecular Weight	34
2.1.2	Homopolymerization and Copolymerization	38
2.2	Intermolecular Binding Energies (Secondary Valence Bonds)	40
2.2.1	Absorption of Water by Polyamides	41
2.3	Spatial Arrangement of Atoms and Groups of Atoms in Molecules (Configuration)	47
2.3.1	Tacticity	48
2.3.2	Branching	48
2.3.3	Cross-Linking	49
2.4	Architecture of Polymer Systems	50
2.4.1	Homogeneous and Heterogeneous Polymer Mixtures	50
2.4.2	Plasticization	51
2.4.3	Fillers and Reinforcement	51
2.5	Morphology (Supermolecular Structures)	54
2.5.1	Amorphous Microstructure	54
2.5.2	Crystalline Microstructure	55
2.5.3	Anisotropy	60
2.5.3.1	Molecular Alignments	60
2.5.3.2	Filler or Fiber Alignment	62
2.6	Thermomechanical Ranges	64
2.6.1	Thermoplastics with Amorphous Structure	64
2.6.2	Thermoplastics with Semicrystalline Structure	66
2.6.3	Elastomers	67
2.6.4	Thermosets	67
3	Brief Description of the Properties of Generic Polymeric Materials	71
3.1	Thermoplastics	71
3.1.1	Polymer Blends	80
3.1.2	Functional Polymers	83
3.2	Elastomers	88

3.3	Thermosets	90
3.4	Fibrous Reinforcements	94
3.4.1	Glass Fibers	95
3.4.1.1	Production and Reinforcing Forms of Glass Fiber Material ..	95
3.4.1.2	Types of Glass and Fiber Properties	96
3.4.2	Carbon Fibers	97
3.4.3	Aramid Fibers	97
3.4.4	Metal Fibers, Whiskers, and Ceramic Fibers	97
4	Physical Properties – Characteristic Values – Test Methods and Procedures	101
4.1	Deformation Behavior under Uniaxial Dynamic Tensile Stress (Stress-Strain Experiments)	101
4.1.1	Molecular Deformation and Fracture Mechanisms	101
4.1.2	Characteristic Stress-Strain Curves	103
4.1.3	Determination of Stress-Strain Diagrams and Characteristic Properties of Materials	104
4.1.4	Effects of Temperature, Time, and Humidity on Stress-Strain Curves	107
4.1.5	Mathematical Description of Stress-Strain Curves	109
4.2	Deformation Behavior under Uniaxial, Long-Term, Static Tensile Loads (Tensile Creep Testing)	111
4.2.1	Mathematical Description of Creep Curves	113
4.3	Toughness and Impact Resistance	115
4.3.1	Determination of Tensile Stress-Strain Toughness	116
4.3.2	Determination of Toughness by Flexural Impact Test	116
4.3.3	Penetration or Dart Drop Impact Test	119
4.4	Behavior under Cyclic Loads	120
4.4.1	Determination of Characteristic Features of Fatigue	122
4.5	Poisson’s Ratio	125
4.6	Thermal Properties	127
4.6.1	Thermal Expansion	127
4.6.2	Dimensional Stability	129
4.6.2.1	Modulus of Elasticity and Modulus of Rigidity as a Function of Temperature	129
4.6.2.2	Deflection Temperature	130
4.6.2.3	Softening Point	131
4.6.3	Heat Aging	132
4.6.3.1	Safety Considerations and Standards	135
4.6.4	Summary Analysis of the Effects of Temperature	136
4.7	Tribological Properties	136
4.7.1	Fundamentals	138
4.7.1.1	Adhesion and Surface Energy of Solids	139
4.7.1.2	Deformation and Hysteresis Loss	144
4.7.1.3	Boundary Conditions for Adhesive and Deformative Sliding	145
4.7.2	Friction and Wear in Mated Polymer and Steel Surfaces	145
4.7.2.1	Effect of Steel Surface Roughness on Steel/Polymer Combinations	147

4.7.2.2	Effect of Relative Molecular Weight on Friction and Wear ..	150
4.7.2.3	Effect of the Moisture Content of Polyamides on Friction and Wear	151
4.7.2.4	Effect of High-Energy Radiation	153
4.7.2.5	Effect of Form and Sequence of Motion on Friction and Wear	155
4.7.3	Friction and Wear in Mated Pairs of Polymeric Materials	156
4.7.3.1	Sliding Friction	156
4.7.3.2	Wear Due to Sliding Friction for Mated Polymeric Material Pairs	157
4.7.4.2	The Effects of Physical Properties on Friction and Wear System Properties	158
4.7.5	Effect of Additives on Friction and Wear Properties	158
4.7.5.1	Effect of Fibers on Wear	159
4.7.5.2	Effect of Other Inorganic Additives	163
4.7.5.3	Effect of Polymeric Additives	163
4.7.6	Stick-Slip	165
4.7.6.1	Changing Stick-Slip Behavior by Modifying the Parameters of the Sliding System	166
4.7.7	Jet Erosion	168

5 Calculations for Structures under Mechanical Load –

	Examples of Geometrically Simple Structural Parts under Static Loads	175
5.1	Specific Materials and Processing Problems	175
5.1.1	Deformation Behavior under Uniaxial Dynamic Tensile Stress	175
5.2	Determination of Strength	177
5.2.1	Basic Procedure for Structural Part Design	177
5.2.1.1	Characteristic Strength	178
5.2.1.2	Safety Factors	180
5.2.1.3	Reducing Factors	181
5.2.2	Uniaxial State of Stress	182
5.2.2.1	Example of a Thin-Walled Pipe under Internal Pressure ..	183
5.2.3	Multiaxial State of Stress	184
5.2.3.1	Failure Criteria	184
5.2.3.2	Examples of Shear Loads	187
5.3	Calculation of Strains and Deformations	190
5.3.1	Linear Elastic Behavior	190
5.3.2	Nonlinear Elastic Behavior	191
5.4	Analysis of Stress and Deformation in Structures under Flexural Loads with the Aid of a Simple FE Approach	196
5.5	Calculation of Structural Parts Subjected to Impact Loads	198
5.6	Structural Design of Fiber-Composite Structures	199
5.6.1	Mechanical Properties of Laminates	200
5.6.1.1	Deformation Behavior under Uniaxial Tensile Load, Damage Limit	200
5.6.1.2	Fundamental Elasticity Variables in a UD Layer	200

5.6.1.3	Averaged Characteristic Values for Mat Laminates	202
5.6.2	Methods of Calculation	205
5.6.2.1	Calculation of Averaged Values	205
5.6.2.2	Continuum Theory	205
5.6.2.3	Network Theory	205
5.7	Computer-Aided Development	207
5.7.1	Computer-Aided Design (CAD)	207
5.7.2	Rapid Prototyping	208
5.7.3	Rapid Tooling	210
6	Design and Material Considerations for Parts Subjected to Mechanical Loads	213
6.1	Flexible Structures	213
6.1.1	Modulus of Elasticity	213
6.1.2	Design Geometry – Moment of Inertia	214
6.1.3	Load–Geometry Interactions	215
6.2	Flexurally Rigid Structures	218
6.3	Flexurally Flexible, Torsionally Rigid Structures	220
6.4	Flexurally Rigid, Torsionally Flexible Structures	221
6.5	Torsion-Resistant, Torsionally Rigid Structures	221
6.6	Flexurally and Torsionally Rigid Structures	224
6.7	Torsionally Flexible Structures	225
6.8	Tension-Proof, Tensionally Rigid and Torsionally Flexible Structures	225
6.9	High Shear-Strength, Shear-Resistant Structures	226
6.10	Pressure-Yielding and Compression-Resistant Structures	227
6.11	Multifunctional Structures	229
6.12	Thermal Expansion and Thermal Stress	230
6.13	Universal Joints	235
7	Designing for Production	239
7.1	Mold Filling	239
7.1.1	Simulation of the Filling Operation	241
7.1.2	Causes of Orientation in Moldings	243
7.1.2.1	Effects of Orientation	246
7.1.2.2	Controlling Orientation	248
7.1.3	Causes for Formation of Weld Lines and Air Pockets	252
7.1.3.1	Effects of Weld Lines and Air Pockets	254
7.1.3.2	Controlling Weld Lines and Air Pockets	255
7.2	Cooling and Solidification	261
7.2.1	Cooling Rate	261
7.2.1.1	Effects of Cooling Rate	261
7.2.1.2	Controlling the Cooling Rate	261
7.2.2	Changes in Dimensions and Tolerances	264
7.2.2.1	Shrinkage	264
7.2.2.2	Post Molding Shrinkage	267
7.2.2.3	Tolerances	267
7.2.3	Warpage	271

7.2.3.1	Causes of Warpage	271
7.2.3.2	Controlling Warpage	274
7.3	Demolding	277
7.3.1	Draft	280
7.3.2	Demolding of Undercuts	280
7.3.2.1	Forced Demolding	281
7.3.2.2	Mold-Making Measures	281
7.3.2.3	Fusible Cores	283
7.3.3	Avoidance of Undercuts	285
7.3.3.1	Modifying the Design	285
7.3.3.2	Piercing Cores (Blocking or Shutoffs)	285
7.3.3.3	Multipart Designs	287
7.4	Sandwich Molding (Co-Injection Molding)	289
7.4.1	Two-Color Injection Molding	289
7.4.2	Rigid-Flexible Combinations	293
7.4.3	Gas Injection Technology (GIT)	299
7.4.5	External Gas Pressure Technology	303
8	Flexing Elements	311
8.1	Snap-Fit Joints	311
8.1.1	Snap-Fit Beams	317
8.1.1.1	Types of Snap-Fit Beams	317
8.1.1.2	Snap-Fit Beam Calculations	321
8.1.1.3	Additional Functions	322
8.1.2	Torsional Snap-Fit Joints	325
8.1.2.1	Types of Torsional Snap-Fit Joints	325
8.1.2.2	Torsion Snap-Fit Joint Calculations	326
8.1.3	Annular Snap-Fit Joints	327
8.1.3.1	Types of Annular Snap-Fit Joints	327
8.1.3.2	Annular Snap-Fit Joint Calculations	328
8.1.3.3	Additional Functions	330
8.1.4	Segmented Annular Snap-Fit Joints	331
8.1.4.1	Segmented Annular Snap-Fits	332
8.1.4.2	Slotted Annular Snap-Fit Joint Calculations	332
8.1.4.3	Additional Functions	334
8.2	Elastic Elements	335
8.2.1	Elastic Thermoplastic Materials	335
8.2.1.1	Flexing Springs	335
8.2.1.2	Tension Springs	337
8.2.1.3	Compression Springs	337
8.2.1.4	Torsion Springs	341
8.2.2	Springs Made of Fiber-Plastic Composites (Glass-Fiber and Carbon-Fiber Reinforced Plastic)	342
8.2.2.1	Leaf Springs	342
8.3	Integral Hinges and Integral Joints	345
8.3.1	Manufacture of Integral Hinges and Integral Joints	346

8.3.1.1	Injection Molding	346
8.3.1.2	Blow Molding	347
8.3.1.3	Embossing	349
8.3.2	Design	349
8.3.3	Materials	350
8.3.4	Integral Hinge Design Calculations	350
8.3.4.1	Calculation of the Length and Thickness of an Integral Hinge	352
8.3.5	Applications with Integral Hinges	355
8.3.5.1	Lid/Container Hinge Joints	355
8.3.5.2	Bi-Stable Hinge Joints	355
8.3.5.3	Simplified Production	357
8.3.5.4	Dynamically Loaded Integral Hinge Joints	361
8.3.5.5	Assembly Aid and Captive Binding Using Integral Hinges	361
9	Mechanical Fasteners	365
9.1	Molded Threads and Threads Produced by Machining	366
9.1.1	Screws and Bolts Made of Polymeric Material	366
9.1.2	Injection-Molded, Blow-Molded, and Machined Threads	368
9.2	Threaded Inserts	368
9.2.1	Encapsulated Threaded Inserts	368
9.2.2	Threaded Inserts Embedded by Ultrasound	368
9.2.3	Press-In Threaded Inserts	369
9.2.4	Expansion Inserts	370
9.2.5	Screw-In Inserts	370
9.2.6	Inserts Made of Polymeric Materials	371
9.2.7	Comparative Evaluation of the Various Inserts	371
9.2.8	Behavior under Dynamic Loads	374
9.3	Self-Threading Screws	374
9.3.1	Screw Shapes and Geometries	375
9.3.1.1	Included Thread Angle	377
9.3.1.2	Self-Locking Screw Threads	377
9.3.2	Design of the Screw Boss	377
9.3.2.1	Screw Engagement Depth	378
9.3.2.2	Boss Pilot Hole Diameter	378
9.3.2.3	Boss Relief Bore	379
9.3.2.4	Boss Outer Diameter	379
9.3.3	Calculation of Key Variables in a Self-Threading Screw Joint	381
9.3.3.1	Screw Drive Torque	381
9.3.3.2	Destruction Torque	383
9.3.3.3	Screw Extraction (Pull-Out) Force	383
9.3.3.4	Tightening Moment and Tensioning Force	384
9.3.3.5	Assembly Conditions	385
10	Ribbed Structures	387
10.1	Comparison with Other Methods of Reinforcement	387

10.1.1	Increasing the Modulus of Elasticity	387
10.1.2	Increasing Wall Thickness	388
10.1.3	Crimps and Corrugations	389
10.2	General Considerations in Ribbed Structures	390
10.2.1	Rib Height	390
10.2.2	Rib Position	391
10.2.3	Number of Ribs (Consumption of Material)	393
10.2.4	Support	395
10.3	Design Rules for Injection-Molded Ribs	396
10.3.1	Rib Thickness	396
10.3.2	Cooling Time	397
10.3.3	Injection Direction	398
10.3.4	Rib Intersection Points (Nodes)	400
10.4	Design Rules for Ribs Produced by Gas-Assist Molding Methods	401
10.5	Design Rules for Blow-Molded Ribs and Corrugations	403
10.5.1	Blow-Molded Corrugations	403
10.5.2	Blow-Molded Ribs	405
10.6	Design Rules for Compression-Molded Ribs	406
10.6.1	Manual Processing (Hand Lay-Up Process)	406
10.6.2	Compression Molding	407
11	Gear Wheels	411
11.1	Calculation of the Tooth and Tooth Face Temperatures in Spur Gears	413
11.1.1	Blok's Flash Temperature Hypothesis	414
11.1.2	Takanashi Method for Calculating Temperature	414
11.1.3	Hachmann and Strickle Method for Calculating Temperature	416
11.1.4	Comparison of Methods of Calculating Temperature	418
11.1.5	Optimized Temperature Calculation	419
11.1.5.1	Speed of Rotation	420
11.1.5.2	Flank Temperature	420
11.1.5.3	Relative Contact Time	422
11.1.5.4	Optimized Numerical Value Equation	423
11.2	Calculation of Load-Bearing Capacity	424
11.2.1	Tooth Damage	425
11.2.2	General Parameters	426
11.2.3	Calculation of the Load-Bearing Capacity of the Tooth Base	427
11.2.4	Calculation of the Load-Bearing Capacity of the Tooth Flank	434
11.2.5	Calculation of Tooth Deformation	440
11.3	Design	442
11.3.1	Injection Molding	442
11.3.2	Production of Gears by Machining	446
11.3.3	Shaft-Hub Joints	447
11.3.3.1	Press-Fit Joints	447
11.3.3.2	Form-Grip Joints	450
11.3.3.3	Pretensioned Form-Grip Joints	452

12 Friction Bearings	459
12.1 Friction Bearing Damage	461
12.2 Calculation of Load-Bearing Capacity for Bearings	463
12.2.1 Calculation of Mean Bearing Temperature	463
12.2.2 Calculation of Temperature of Sliding Surface	466
12.2.3 Static Load-Bearing Capacity	466
12.2.3.1 Load on the Bearing Material	467
12.2.3.2 Deformation of the Bearing Bushing	471
12.2.4 Dynamic Load-Bearing Capacity	475
12.2.4.1 Continuous Operation	475
12.2.4.2 Intermittent Operation	476
12.2.4.3 Wear	477
12.3 Bearing Design	478
12.3.1 Bearing Clearance	478
12.3.2 Bearing Wall Thickness	480
12.3.3 Bearing Production	481
12.3.4 Design Examples of Bearings	481
13 Wheels and Rollers	485
13.1 Roller Damage	486
13.2 Calculation of Load-Bearing Capacity	488
13.2.1 Pressure Parameter as an Approximate Design Limit	488
13.2.2 Deformation of Rollers under Static Load	492
13.2.3 Rollers under Dynamic Load	498
13.2.3.1 Free-Wheeling Rollers (without Drive)	498
13.2.3.2 Driven Rollers	504
Index	509