

Contents

1	Rapid Guidelines for Joining of Plastics and Efficient Use of This Handbook	1
1.1	Efficient Use of This Handbook	1
1.2	Rapid Guidelines for Assembly of Plastics	2
1.2.1	Adhesives (Chapter 7)	2
1.2.1.1	Liquids: Solvent-Based, Water-Based, and Anaerobic Adhesives	2
1.2.1.2	Mastics	3
1.2.1.3	Hot Melts	3
1.2.1.4	Pressure-Sensitive Adhesives	3
1.2.2	Fasteners and Inserts (Chapter 8)	3
1.2.3	Hinges (Chapter 9)	4
1.2.4	Hot Plate/Hot Die/Fusion and Hot Wire/Resistance Welding (Chapter 10)	4
1.2.5	Hot Gas Welding (Chapter 11)	5
1.2.6	Induction Welding (Chapter 12)	5
1.2.7	Insert Molding (Chapter 13)	5
1.2.8	Multipart Molding (Chapter 13)	6
1.2.9	Press Fits/Force Fits/Interference Fits/Shrink Fits (Chapter 14)	6
1.2.10	Solvent Joining (Chapter 7)	6
1.2.11	Snap Fits (Chapter 15)	7
1.2.12	Spin Welding (Chapter 16)	7
1.2.13	Staking/Swaging/Peening/Cold Heading/Cold Forming (Chapter 17)	7
1.2.14	Threads – Molded in (Chapter 18)	8
1.2.15	Threads – Tapped (Chapter 18)	8
1.2.16	Ultrasonic Welding (Chapter 19)	8
1.2.17	Vibration Welding (Chapter 20)	9
1.3	Assembly Methods Selection by Size	9
1.4	Assembly Methods Selection by Joining Time	11
2	Designing for Efficient Assembly	12
2.1	Avoiding Part Distortion	12
2.2	Inside Corner Stress	13
2.3	Ribs and Bosses	14
2.4	Draft	15
2.5	Shrinkage	17
2.6	Fitments	19
2.6.1	Drawing Conventions for Plastic Assembly	19
2.6.2	Importance of Tolerancing for Assembly	21
2.6.3	Special Drafting Practices for Plastics	22
2.6.4	Procedure for Establishing Tolerances	26
2.7	Design Practices for Looser Tolerances in Plastics	27
2.7.1	Three-Point Location	28
2.7.2	Hollow Bosses	28

2.7.3	Crush Ribs	30
2.7.4	Flexible Ribs	31
2.7.5	Inside/Outside Fitments.	32
2.7.6	Step Fitments	32
2.8	More Relaxed Tolerances for Large Parts	33
2.8.1	Drill in Place	33
2.8.2	Oversize Hole with Washer	33
2.8.3	Criss-cross Slots	33
2.8.4	Separation of Functions	34
2.8.5	Corner Clearance	34
2.9	Semidovetail Joint	35
2.10	Minimizing the Effect of Misalignment on Appearance.	36
2.11	The Plastic Product Design for Assembly Checklist	36
2.12	Testing	36
3	Cost Reduction in Assembly.	40
3.1	Introduction.	40
3.2	The Micro Approach to Part Reduction	40
3.2.1	Combining Parts Through Materials	41
3.2.2	Combining Parts Through Processes	42
3.3	The Macro Approach to Part Reduction.	43
3.3.1	Multiple Material Processing	47
3.3.2	Coextrusion.	48
3.3.3	Coinjection Molding	49
3.3.4	Multipart or Two-Color Injection Molding	49
3.4	Elimination of Fasteners	49
3.4.1	Multiple Parts per Fastener	50
3.4.2	Press and Snap Fits	50
3.4.3	Integral Hinges	51
3.4.4	Combining Fastener Elimination Concepts	52
3.5	Holistic Design	53
3.5.1	The Overall Design Considerations.	53
3.5.2	The Thread Design.	54
3.5.3	The Processing Considerations.	55
3.5.4	The Tooling Considerations	56
3.5.5	Execution.	56
3.5.6	Toward Holistic Design.	57
4	Design for Disassembly and Recycling	58
4.1	Introduction.	58
4.2	Design for Disassembly	59
4.2.1	Reopenable Assemblies	59
4.2.2	Permanent Assemblies	63
4.3	Design for Recycling	65
4.3.1	Simplification	65
4.3.2	Assembly Method Selection	65
4.3.2.1	Reopenable Methods	65
4.3.2.2	Permanent Methods	66

4.3.3	Material Selection	66
4.3.4	Additives.	67
4.3.5	Contaminants.	68
4.3.6	Material Reduction	68
4.3.7	Identification and Disassembly Instructions	70
5	Assembly Method Selection by Material	71
5.1	Thermoplastics Versus Thermosets	71
5.2	Amorphous Versus Semicrystalline Thermoplastics	72
5.2.1	Postmolding Shrinkage.	73
5.2.2	Coefficient of Linear Thermal Expansion	73
5.2.3	Weldability.	74
5.2.4	Solvent Sealability.	74
5.3	Thermosets	74
5.4	Assembly Method by Material.	75
5.4.1	Properties and Assembly-Related Data for Selected Materials	76
5.4.2	Adhesives	108
5.4.3	Using the SPI Tables.	109
6	Assembly Method Selection by Process.	150
6.1	Introduction	150
6.2	Blow Molding.	150
6.2.1	The Process	150
6.2.2	Assembly Considerations	151
6.3	Casting, Potting Encapsulation, and Embedment	152
6.3.1	The Processes.	152
6.3.2	Assembly Considerations	153
6.4	Coextrusion.	153
6.5	Co-Injection Molding	153
6.6	Cold Press Molding	153
6.6.1	The Process	153
6.6.2	Assembly Considerations	154
6.7	Compression Molding	155
6.7.1	The Process	155
6.7.2	BMC: Bulk Molding Compound	155
6.7.3	SMC: Sheet Molding Compound	155
6.7.4	Assembly Considerations	155
6.8	Extrusion.	156
6.8.1	The Process	156
6.8.2	Coextrusion	157
6.8.3	Assembly Considerations	158
6.9	Filament Winding	159
6.9.1	The Process	159
6.9.2	Assembly Considerations	160
6.10	Gas-Assisted Injection Molding	160
6.11	Gas Counter Pressure Structural Foam Molding	160

6.12	Injection Molding	160
6.12.1	The Process	160
6.12.2	Assembly Considerations	161
6.13	Lay-up and Spray-up	162
6.13.1	The Processes	162
6.13.2	Assembly Considerations	162
6.14	Machining	163
6.14.1	The Process	163
6.14.2	Thermoplastics	164
6.14.3	Thermosets	165
6.14.4	Assembly Considerations	165
6.15	Pultrusion	165
6.15.1	The Process	165
6.15.2	Assembly Considerations	166
6.16	Reaction Injection Molding (RIM)	167
6.16.1	The Process	167
6.16.2	Assembly Considerations	168
6.17	Resin Transfer Molding (RTM)	168
6.17.1	The Process	168
6.17.2	Assembly Considerations	169
6.18	Rotational Molding	170
6.18.1	The Process	170
6.18.2	Assembly Considerations	171
6.19	Structural Foam Molding, Gas Counterpressure Structural Foam Molding, and Coinjection Molding	172
6.19.1	The Processes	172
6.19.2	Assembly Considerations	174
6.20	Thermoforming	175
6.20.1	The Processes	175
6.20.2	Thin-Gauge Thermoforming	176
6.20.3	Heavy-Gauge Thermoforming	177
6.20.4	Pressure Thermoforming	177
6.20.5	Other Forming Processes	178
6.20.6	Assembly Considerations	178
6.21	Twin-Sheet Thermoforming	179
6.21.1	The Process	179
6.21.2	Assembly Considerations	179
6.22	Transfer Molding	179
6.22.1	The Process	179
6.22.2	Assembly Considerations	180
6.23	Process Selection	180
6.23.1	Thermoplastic Open Shapes	182
6.23.2	Thermoset Open Shapes	183
6.23.3	Hollow Parts	184
6.23.4	Profiles	185
6.23.5	Ultra High Strength	185

7	Adhesive and Solvent Joining	186
7.1	Advantages and Disadvantages	186
7.1.1	Advantages	186
7.1.2	Disadvantages	188
7.2	Basic Theory and Terminology	189
7.3	Methods for Measuring the Wettability of a Plastic Surface	190
7.3.1	Contact Angle Test	190
7.3.2	Wetting Tension Test (ASTM D-2578-73, Wetting Tension of Polyethylene and Polypropylene Films)	191
7.3.3	Adhesion Ratio Test (Tentative ASTM D-2141-63R)	191
7.3.4	Water Spreading Test	192
7.3.5	Dye Stain Test	192
7.3.6	Ink Retention Test	193
7.4	Surface Treatments	193
7.4.1	Solvent Cleaning	193
7.4.1.1	Solvent Immersion	194
7.4.1.2	Solvent Wiping	194
7.4.1.3	Solvent Spray	195
7.4.1.4	Vapor Degreasing	195
7.4.1.5	Ultrasonic Vapor Degreasing	195
7.4.1.6	Ultrasonic Cleaning with Liquid Rinse	195
7.4.2	Abrasive Methods	195
7.4.2.1	Dry Abrasion	195
7.4.2.2	Dry Abrasive Blast	196
7.4.2.3	Wet Abrasive Blast	196
7.4.2.4	Wet Abrasive Scour	196
7.4.2.5	Detergent Scrub	196
7.4.3	Surface Energy Treatments and Process Selection Factors	197
7.4.3.1	Chemical Treatment	197
7.4.3.2	Corona Treatment	197
7.4.3.3	Plasma Treatment	198
7.4.3.4	Flame Treatment	199
7.4.3.5	Process Selection Factors	199
7.4.4	Shelf Life of Surface Treatments	200
7.5	Design for Adhesion	200
7.5.1	Shear Stress	200
7.5.2	Tensile Stress	201
7.5.3	Cleavage	201
7.5.4	Peel	201
7.5.5	Adhesive Joint Designs	201
7.5.5.1	Load-Bearing or Non-Load-Bearing Joints	201
7.5.5.2	Lap Joints	202
7.5.5.3	Butt Joints	207
7.5.5.4	Screw and Glue	210
7.6	Adhesives	211
7.6.1	Acrylics	211
7.6.2	Anaerobics	212
7.6.3	Cyanoacrylates	218

7.6.4	Epoxies	219
7.6.5	Hot Melts	219
7.6.6	Phenolics	220
7.6.7	Polyurethanes	220
7.6.8	Polysulfides	221
7.6.9	Pressure-Sensitive Adhesives	221
7.6.10	Silicones	221
7.6.11	Solvent-Based Adhesives	221
7.6.12	Water-Based Adhesives	222
7.7	Solvents	222
7.8	Adhesive and Solvent Assembly Techniques	224
7.8.1	Fixturing	224
7.8.2	Clamping	225
7.8.3	Application Methods	226
	7.8.3.1 Capillary Method	227
	7.8.3.2 Dip or Soak Method	227
7.9	Adhesive and Solvent System Selection	228
7.10	Glossary	230
7.11	Sources	232
8	Fasteners and Inserts	235
8.1	Advantages and Disadvantages	235
8.1.1	Advantages of Using Fasteners	235
8.1.2	Disadvantages of Using Fasteners	235
8.2	Basic Design Considerations for Fasteners	237
8.2.1	Creep Effects	237
8.2.2	Stress Relaxation Effects	238
8.2.3	Notch Sensitivity	238
8.2.4	Craze Resistance	239
8.2.5	Stiffness Considerations	240
8.2.6	Differentials in the Coefficients of Linear Thermal Expansion	240
8.2.7	Loss of Properties Due to Moisture	241
8.2.8	Clamp Load	241
	8.2.8.1 Strain Method	241
	8.2.8.2 Torque Method	242
8.2.9	Vibration Resistance	243
8.3	Methods of Using Fasteners with Plastics	243
8.3.1	Press-in Fasteners	244
8.3.2	Self-Tapping Screws	245
	8.3.2.1 Strength of Plastic Threads	245
	8.3.2.2 Thread-Forming and Thread-Cutting Screws	247
8.3.3	Special Screws for Plastics	249
	8.3.3.1 Narrow Thread Forms	250
	8.3.3.2 Alternating Thread Heights	250
	8.3.3.3 Asymmetrical Thread Forms	250
8.4	Selection of Self-Tapping Screws	250
8.4.1	Cost Criteria	250
8.4.2	Fail/Drive Ratio and Differential	251

8.4.3	Strength Criteria	251
8.4.4	Thread Cutting or Thread Forming	252
8.4.5	Tapped or Molded-in Threads.	253
8.5	Threaded Inserts: Advantages	254
8.6	Boss Cap	255
8.7	Helical Coil Inserts.	255
8.8	Self-Tapping Inserts	256
8.9	Press-in Inserts	256
8.10	Glue-in Inserts	257
8.11	Expansion Inserts	257
8.12	Molded-in Inserts	258
8.13	Ultrasonic Inserts	258
8.14	Heat-Installed Inserts.	261
8.15	Induction Inserts	262
8.16	Hermetic Seals	263
8.17	Studs	263
8.18	Insert Design Considerations	263
8.19	U- or J-Clips	264
8.20	Tee Nuts	265
8.21	Machine Screws	265
8.22	Tapping and Stud Plates	267
8.23	Plastic Screws	267
8.24	Screw Heads and Washers	268
8.25	Boss Designs	268
8.25.1	Design Criteria	268
8.25.2	Boss Sinks	269
8.25.2.1	Coring	269
8.25.2.2	Location	271
8.25.2.3	Support	271
8.25.2.4	Material	272
8.25.2.5	Surface Treatment	272
8.25.3	Weld Lines	272
8.26	Self-Threading Nuts	274
8.27	Twist Nuts	274
8.28	Press-on Nuts	274
8.29	Spring Clips.	275
8.30	Push-in Fasteners	275
8.31	Rivets	275
8.32	Sources.	277
8.32.1	Fasteners.	277
8.32.2	Threaded Inserts	278
8.32.3	Thermal Insertion Equipment	279
8.32.4	Induction Insertion Equipment	279
8.32.5	Ultrasonic Insertion Equipment	279
9	Hinges	280
9.1	Advantages and Disadvantages	280
9.1.1	Advantages.	280
9.1.2	Disadvantages	280

9.2	One-Piece Integral Hinges	280
9.2.1	The Living Hinge	281
9.2.1.1	Living Hinge Design	282
9.2.1.2	Living Hinge Molding Considerations.	285
9.2.1.3	Living Hinges by Other Processes	289
9.2.2	The Mira Spring Hinge	292
9.2.3	Standard Hinges	294
9.2.4	Tab Hinges	294
9.3	Two-Piece Plastic Hinges	294
9.3.1	Ball-and-socket Hinges	295
9.3.2	Two-Piece Lug-and-Pin Joint	296
9.3.3	Hook-and-Eye Joint	296
9.4	Three-Piece Hinges	297
9.4.1	Three-Piece Lug and Pin	297
9.4.2	Piano Hinge	298
9.5	Latches	298
9.5.1	Snaps	298
9.5.2	Rathbun Spring	298
9.6	Number of Hinges and Location	298
10	Hot Plate/Hot Die/Fusion and Hot Wire/Resistance Welding	300
10.1	Advantages and Disadvantages	300
10.1.1	Description	300
10.1.2	Advantages	300
10.1.3	Disadvantages	301
10.2	Materials	302
10.3	The Process	303
10.4	Types of Hot Plate Welding	307
10.4.1	Low Temperature Hot Plate Welding	307
10.4.2	High Temperature Hot Plate Welding	307
10.4.3	Noncontact Hot Plate Welding	308
10.5	Hot Plate Welding Joint Designs	308
10.6	Equipment	310
10.7	Hot Wire/Resistance Welding	311
10.8	Sources.	312
11	Hot Gas Welding	313
11.1	Advantages and Disadvantages	313
11.1.1	Advantages	313
11.1.2	Disadvantages	313
11.2	The Process	314
11.2.1	Tack Welding	314
11.2.2	Permanent Hot Gas Welding.	315
11.2.3	High Speed Welding	316
11.2.4	Extrusion Welding	318
11.3	Joint Designs	318

11.4	Welding Practice	320
11.4.1	Appearance Problems.	321
11.4.2	Cracking Problems	322
11.4.3	Distortion	322
11.4.4	Fusion Problems.	322
11.4.5	Penetration	323
11.4.6	Porosity	323
11.4.7	Scorching	323
11.5	Testing the Weld	323
11.5.1	Nondestructive Testing	323
11.5.1.1	Visual Examination	323
11.5.1.2	Leak Tests	324
11.5.2	Destructive Tests.	324
11.5.2.1	Tensile Test	324
11.5.2.2	Bending Test	324
11.5.2.3	Rod Removal Test	324
11.5.3	Chemical Test	325
11.5.4	Spark Test	325
11.6	Applications	325
11.7	Sources	325
11.7.1	Welding Rods	325
11.7.2	Welding Equipment	325
11.7.3	Welding Rod and Equipment	326
12	Induction/Electromagnetic Welding	327
12.1	Description	327
12.2	Advantages and Disadvantages	327
12.2.1	Advantages	327
12.2.2	Disadvantages	328
12.3	The Equipment	329
12.4	The Process.	331
12.5	The Coil	332
12.5.1	Single-Turn Coils	332
12.5.2	Hairpin Coils	332
12.5.3	Multi-Turn Coils.	333
12.5.4	Split Coils	334
12.5.5	Other Types of Coils	334
12.5.6	Coil Positioning	334
12.5.7	Flux Concentrators.	335
12.6	Materials.	335
12.6.1	Polymers	335
12.6.2	The Electromagnetic Material	335
12.6.2.1	Molded-in Pre-Forms	336
12.6.2.2	Hot Melt Electromagnetic Materials	337
12.6.2.3	Liquid Electromagnetic Materials	337
12.7	Joint Designs	337
12.8	Encapsulation.	340

12.9	Film and Sheetting	340
12.9.1	Intermittent Sealing	341
12.9.2	Continuous Sealing	341
12.10	Inserting Metal into Plastic	341
12.11	Sources	342
13	Insert and Multipart Molding	343
13.1	Description	343
13.2	Insert Molding	343
13.2.1	Advantages of Insert Molding	343
13.2.2	Disadvantages of Insert Molding	344
13.2.3	Design with Threaded Inserts	345
13.2.4	Mold Considerations for Threaded Inserts	348
13.2.5	Custom-Designed Inserts	350
13.2.6	Outserts: Inserts Larger than the Moldment	354
13.2.7	Hermetic Seals	355
13.2.8	Preparation of Inserts	356
13.2.9	Decorative Inserts	356
13.3	Multi-Part Molding	358
13.3.1	Description	358
13.3.2	Advantages Particular to Multipart Molding	359
13.3.3	Disadvantages Particular to Multipart Molding	359
13.3.4	The Process	360
13.3.5	Materials	361
13.4	Sources	363
14	Press Fits/Force Fits/Interference Fits/Shrink Fits	364
14.1	Advantages and Disadvantages	364
14.1.1	Advantages	364
14.1.2	Disadvantages	364
14.2	Press Fit Engineering	365
14.2.1	Engineering Notation	365
14.2.2	Geometric Factor	366
14.2.3	Changes Due to Temperature Variations	366
14.2.4	Hoop Stress	367
14.2.4.1	Metal Shaft in Plastic Boss	367
14.2.4.2	Shaft and Boss of Same Material	368
14.2.4.3	Shaft and Boss of Different Plastics	368
14.2.4.4	Quick Methods	368
14.2.5	Assembly and Disassembly Forces	369
14.2.6	Dimensional Changes Due to Assembly	370
14.2.7	Relationships	370
14.2.8	Equation Limitations	370
14.3	Safety Factor	376
14.4	Processing	376
14.5	Material Selection	376

14.6	Part Design	377
	14.6.1 Heavy-Duty Press Fits	377
	14.6.2 Light-Duty or Reopenable Press Fits	377
	14.6.3 Other than Round	378
15	Snap Fits	380
	15.1 Advantages and Disadvantages	380
	15.1.1 Advantages	380
	15.1.2 Disadvantages	381
	15.2 General Applications	382
	15.3 General Engineering Principles	382
	15.3.1 Allowable Dynamic Strain	382
	15.3.2 Corner Stress Concentrations	383
	15.3.3 Engineering Adjustments When Both Parts Are Elastic	384
	15.3.4 Finite Element Analysis	385
	15.4 Cantilever Snap Fits	385
	15.4.1 Cantilever Snap Fit Designs	385
	15.4.2 Cantilever Snap Fit Engineering	388
	15.5 Cylindrical, Ring, Perimeter, or Annular Snap Fits	394
	15.5.1 Cylindrical Snap Fit Designs	394
	15.5.2 Engineering of Cylindrical, Ring, Perimeter, or Annular Snap Fits	395
	15.5.2.1 Maximum Permissible Interference	395
	15.5.2.2 Transverse and Axial Forces	396
	15.6 Torsion Snap Fits	399
	15.6.1 Torsion Snap Fit Designs	399
	15.6.2 Engineering of Torsion Snap Fits	399
	15.7 Strippable Snap Fits	401
	15.8 The Injection Molding Process	402
	15.9 Molds for Snap Fits	403
	15.9.1 The Basics of Injection Mold Construction	403
	15.9.2 Ejection and Cooling Systems for Stripping Molds	405
	15.9.3 Cores for Nonstripping Molds	407
	15.9.4 Snap Fit Details in the Mold Cavity	409
	15.10 Conclusions	411
16	Spin Welding	413
	16.1 Description of Spin Welding	413
	16.2 Advantages and Disadvantages of Spin Welding	413
	16.2.1 Advantages	413
	16.2.2 Disadvantages	414
	16.3 Spin Welding Process	415
	16.4 Materials	417
	16.5 Design for Spin Welding	419
	16.5.1 Overall Design Considerations	419
	16.5.2 Joint Designs	419

16.6	The Equipment for Spin Welding	421
16.6.1	Drill-Press-Based Spin Welders	421
16.6.1.1	Tooling for Drill-Press-Based Inertial Welding	421
16.6.1.2	Tooling for Drill-Press-Based Pivot Tool Welding	422
16.6.2	Commercial Inertia Spin Welders	422
16.6.3	Commercial Direct-Drive Spin Welders	424
16.7	Sources	426
17	Staking/Swaging/Peening/Cold Heading/Cold Forming	427
17.1	Advantages and Disadvantages of Staking/Cold Forming	427
17.1.1	Advantages	427
17.1.2	Disadvantages	428
17.2	Staking	428
17.2.1	Cold Forming of Stakes	429
17.2.2	Hot Air/Cold Staking	431
17.2.3	Ultrasonic Cold Forming	432
17.2.4	Hot Die Forming of Stakes (Thermal Staking)	434
17.2.5	Ultrasonic Hot Forming of Stakes	434
17.3	Stake Design	435
17.3.1	The Stud	435
17.3.2	Stake Heads	435
17.4	Swaging	439
17.5	Sources	440
17.5.1	Thermal Staking	440
17.5.2	Hot Air/Cold Staking	440
17.5.3	Ultrasonic	440
18	Threads: Tapped and Molded-in	441
18.1	Advantages and Disadvantages of Integral Threads	441
18.1.1	Advantages Common to Threads of Both Types	441
18.1.2	Disadvantages Common to Threads of Both Types	441
18.2	Drilled and Tapped Holes in Plastics	442
18.2.1	Advantages Unique to Tapped Threads	442
18.2.2	Disadvantages Unique to Tapped Threads	442
18.2.3	Drilling Holes in Plastics	443
18.2.4	Reaming Holes in Plastics	444
18.2.5	Tapping Holes in Plastics	444
18.3	Molded Threads in Plastics	447
18.3.1	Advantages Unique to Molded-in Threads	447
18.3.2	Disadvantages Unique to Molded-in Threads	447
18.3.3	Thread Design	447
18.3.4	Molds for Threads	449
18.3.4.1	Stripping Molds for Internal Threads	450
18.3.4.2	Collapsing Core Molds for Internal Threads	451
18.3.4.3	Expandable Cavity Molds for External Threads	453
18.3.4.4	Split-Cavity Molds for External Threads	453
18.3.4.5	Unscrewing Molds for Internal Threads	455
18.3.4.6	Unscrewing Chuck Plate Mold	455
18.3.4.7	Molds for Parts with Less than One Turn of Thread	455

18.4	Sources	456
	18.4.1 Collapsing Cores and Cavities	456
	18.4.2 Unscrewing Chuck	456
19	Ultrasonic Welding	457
19.1	Advantages and Disadvantages of Ultrasonic Welding	457
	19.1.1 Advantages	457
	19.1.2 Disadvantages	458
19.2	General Applications	459
19.3	The Principal of Ultrasonic Welding	459
19.4	Materials for Ultrasonic Welding	460
	19.4.1 Additive and Contaminants	463
	19.4.1.1 Colorants	463
	19.4.1.2 Fillers, Extenders, and Fibrous Reinforcements	463
	19.4.1.3 Flame Retardants	465
	19.4.1.4 Foaming Agents	465
	19.4.1.5 Impact Modifiers	465
	19.4.1.6 Lubricants	465
	19.4.1.7 Mold Releases	466
	19.4.1.8 Painted Parts	466
	19.4.1.9 Plasticizers	466
	19.4.1.10 Regrind	466
19.5	Part Design for Ultrasonic Welding	467
	19.5.1 Overall Ultrasonic Welding Considerations	467
	19.5.1.1 Strength Requirements	467
	19.5.1.2 Appearance Requirements	467
	19.5.1.3 Rigidity Considerations	467
	19.5.2 Joint Fundamentals	470
	19.5.2.1 Part Alignment	470
	19.5.2.2 Uniform Vibration Travel Distance	471
	19.5.2.3 Minimal Initial Contact Area	471
	19.5.3 Energy Director Joints	472
	19.5.3.1 Butt Joint	472
	19.5.3.2 Joint Layout	474
	19.5.3.3 Textured Surface	476
	19.5.3.4 Step Joint	476
	19.5.3.5 Tongue-and-Groove Joint	477
	19.5.3.6 Thin-Walled Joint	478
	19.5.4 Shear Joints	478
	19.5.5 Hermetic Seals	482
	19.5.6 Scan Welding	483
	19.5.7 Stud Welding, Staking, Swaging, and Spot Welding	483
	19.5.7.1 Staking and Swaging	485
	19.5.7.2 Stud Welding	485
	19.5.7.3 Spot Welding	488
19.6	Fabric and Film Sealing	489

19.7	The Ultrasonic Equipment	492
19.7.1	The Basic Principles	492
19.7.2	The Power Supply or Generator	492
19.7.3	The Converter or Transducer.	492
19.7.4	The Booster	493
19.7.5	The Horn	494
19.7.6	The Fixture	496
19.7.7	The Controls	497
19.7.8	Equipment Frequency.	498
19.7.9	Automation of Ultrasonic Welding	499
19.8	Sources.	499
20	Vibration Welding	501
20.1	Advantages and Disadvantages	501
20.1.1	Comparison with Ultrasonic Welding	501
20.1.2	Advantages of Vibration Welding.	501
20.1.3	Disadvantages of Vibration Welding	503
20.2	The Process of Vibration Welding	503
20.2.1	Linear Vibration Welding	505
20.2.2	Orbital Vibration Welding	505
20.2.3	Angular Vibration Welding	506
20.3	Materials	506
20.4	Vibration Welding Part Design.	508
20.4.1	Basic Considerations	508
20.4.2	Joint Designs for Linear Vibration Welding	510
20.5	The Equipment	513
20.6	Sources.	514
	References	515
	Index	521