## Polymers and Plastics

### 1. Thermosets
- Thermosets ........................................... 3

### 1.2 Thermoplastics
- Amorphous and Semi-crystalline Plastics ............ 5

### 2. Commodities

#### 2.1 Polyethylene (PE)
- Classification ........................................ 8
- Properties of Polyethylene .............................. 8
- Recycling ............................................... 9
- Application Areas ..................................... 9

#### 2.2 Polypropylene (PP)
- Properties of Polypropylene ......................... 12
- Recycling ............................................... 13

#### 2.3 Polyvinylchloride (PVC)
- Properties of PVC ..................................... 14
- Recycling ............................................... 14

#### 2.4 Polystyrene (PS)
- Classification ........................................ 16
- Properties of Polystyrene .............................. 16
- Recycling ............................................... 17
- Application Areas ..................................... 17

#### 2.5 Styrene-Acrylonitrile (SAN)

#### 2.6 Acrylonitrile-Butadiene-Styrene (ABS)
- ABS Blends ................................----------- 19
- Properties of ABS ..................................... 19
- Recycling ............................................... 19
- Application Areas ..................................... 20

#### 2.7 Polymethyl Methacrylate (PMMA)
- Properties of PMMA ................................... 22
- Recycling ............................................... 22
- Application Areas ..................................... 22

## Engineering Polymers

### 3.1 Polyamide or Nylon
- Classification ........................................ 23
- Properties of Polyamide ............................... 24
- Recycling ............................................... 25
- Application Areas ..................................... 25
## Contents

5.5 Polyphenylene Sulfide – PPS ........................................... 52
  5.5.1 Properties of PPS .......................................... 52
  5.5.2 Application Areas ........................................ 52

5.6 Polyether Ether Ketone – PEEK .................................. 53
  5.6.1 Properties of PEEK ......................................... 53
  5.6.2 Application Areas ........................................ 54

5.7 Polyetherimide – PEI ............................................. 54
  5.7.1 Properties of PEI ........................................... 55
  5.7.2 Application Areas ........................................ 55

5.8 Polysulfone – PSU ................................................ 56
  5.8.1 Properties of PSU ........................................... 56
  5.8.2 Application Areas ........................................ 57

5.9 Polyphenylsulfone – PPSU ..................................... 57
  5.9.1 Properties of PPSU ......................................... 57
  5.9.2 Application Areas ........................................ 58

### Bioplastics and Biocomposites ........................................... 59

6.1 Definition ............................................................. 59
  6.1.1 What Do We Mean by Bioplastic? ......................... 60

6.2 The Market .......................................................... 60

6.3 Bioplastics ............................................................. 62

6.4 Biopolymers ........................................................... 62

6.5 Biobased Polymers: Biopolyester ............................... 63

6.6 Biobased Polymers: Biopolyamides ............................ 65

6.7 Biobased Polymers from Microorganisms ....................... 66

6.8 Bioethanol or Biomethanol ....................................... 67

6.9 Biocomposites ......................................................... 68

6.10 More Information about Bioplastics .............................. 69

### Plastic and the Environment ............................................. 70

7.1 Plastic is Climate-Friendly and Saves Energy .................. 70

7.2 Environmental Effects on Plastic .................................. 72

7.3 Recycling Plastic ...................................................... 73
  7.3.1 Plastic Recycling in the EU .................................. 74

### Modification of Polymers ............................................... 76

8.1 Polymerization ......................................................... 76

8.2 Additives ............................................................... 78
  8.2.1 Stiffness and Tensile Strength ................................. 79
  8.2.2 Surface Hardness .............................................. 79
  8.2.3 Wear Resistance ................................................ 79
  8.2.4 Toughness ........................................................ 80
## Contents

8.3 Physical Properties ........................................ 80
  8.3.1 Appearance ...................................... 80
  8.3.2 Crystallinity ...................................... 81
  8.3.3 Weather Resistance ................................. 81
  8.3.4 Friction ........................................ 82
  8.3.5 Density ........................................ 82

8.4 Chemical Properties ..................................... 83
  8.4.1 Permeability ..................................... 83
  8.4.2 Oxidation Resistance .............................. 83
  8.4.3 Hydrolysis Resistance .............................. 84

8.5 Electrical Properties ..................................... 84

8.6 Thermal Properties ...................................... 85
  8.6.1 Heat Stabilization ................................ 85
  8.6.2 Heat Deflection Temperature ..................... 86
  8.6.3 Flame Retardant Classification .................... 86

8.7 Material Price ............................................ 87

### CHAPTER 9 Material Data and Measurements ....................... 88

9.1 Tensile Strength and Stiffness ............................. 89
9.2 Impact Strength ........................................ 92
9.3 Maximum Service Temperature ............................ 93
  9.3.1 UL Service Temperature ............................ 93
  9.3.2 Heat Deflection Temperature .................... 93

9.4 Flammability Tests ...................................... 95
  9.4.1 HB Rating ........................................ 95
  9.4.2 V Rating ........................................ 95

9.5 Electrical Properties ..................................... 96
9.6 Flow Properties: Melt Index ............................... 97
9.7 Shrinkage ................................................ 97

### CHAPTER 10 Material Databases on the Internet .................. 98

10.1 CAMPUS ................................................ 98
  10.1.1 Properties of CAMPUS 5.2 ....................... 99
10.2 Material Data Center .................................... 99
  10.2.1 Properties of Material Data Center ............... 100
10.3 Prospector Plasctics Database .......................... 100

### CHAPTER 11 Test Methods for Plastic Raw Materials and Moldings 102

11.1 Quality Control during Raw Material Production .......... 102
11.2 Visual Quality Control of Plastic Granules ............... 103
11.3 Visual Inspection of Plastic Parts ....................... 104
11.4 Tests That Can Be Performed by the Molder .............. 105
11.5 Advanced Testing Methods ................................ 107
Contents

Injection-Molding Methods ................................... 110

12.1 History .......................................................... 110
12.2 Properties ..................................................... 111
  12.2.1 Limitations ................................................. 111
12.3 The Injection-Molding Machine .............................. 112
  12.3.1 The Injection Unit ........................................... 112
  12.3.2 Locking Unit .................................................. 113
  12.3.3 Injection-Molding Cycle ................................. 114
12.4 Alternative Injection-Molding Methods ....................... 115
  12.4.1 Multi-component Injection Molding ..................... 115
  12.4.2 Gas or Water Injection .................................... 116

Post-molding Operations ........................................ 117

13.1 Surface Treatment of Moldings .............................. 117
  13.1.1 Printing ...................................................... 117
  13.1.2 “Hot Stamp” Printing ...................................... 118
  13.1.3 Tampon Printing ............................................ 119
  13.1.4 Screen Printing .............................................. 119
  13.1.5 IMD: In-Mold Decoration ................................. 120
  13.1.6 Laser Marking ............................................... 121
  13.1.7 Painting ..................................................... 121
  13.1.8 Metalizing/Chroming ...................................... 122

Different Types of Molds ......................................... 123

14.1 Two-Plate Molds ............................................... 123
14.2 Three-Plate Molds ............................................. 124
14.3 Molds with Slides ............................................. 124
14.4 Molds with Rotating Cores ................................... 125
14.5 Stack Molds ................................................... 125
14.6 Molds with Ejection from the Fixed Half .................... 126
14.7 Family Molds .................................................. 126
14.8 Multi-component Molds ...................................... 127
14.9 Molds with Melt Cores ....................................... 128

Structure of Molds ................................................ 129

15.1 The Function of the Mold ..................................... 130
15.2 Runner Systems – Cold Runners ............................. 130
15.3 Runner Systems – Hot Runners ............................... 132
15.4 Cold Slug Pockets/Pullers .................................... 133
15.5 Tempering or Cooling Systems .............................. 134
15.6 Venting Systems ............................................... 136
15.7 Ejector Systems ............................................... 137
15.8 Draft Angles ................................................... 138
## Cost Calculations for Moldings

- **19.1 Part Cost Calculator** ........................................ 169
- **19.2 Part Cost Scenarios** ........................................ 173
- **19.2 Replacement Cost** ........................................ 174

## Extrusion

- **20.1 The Extrusion Process** ..................................... 177
  - 20.1.1 Advantages (+) and Limitations (−) ...................... 177
- **20.2 Materials for Extrusion** .................................... 179
- **20.3 The Extruder Design** ....................................... 180
  - 20.3.1 The Cylinder ............................................. 180
  - 20.3.2 Single-Screws ........................................... 181
  - 20.3.3 Barrier Screws .......................................... 181
  - 20.3.4 Straight Twin-Screws .................................... 182
  - 20.3.5 Conical Twin-Screws .................................... 182
  - 20.3.6 Rotational Direction ..................................... 183
  - 20.3.7 Comparison of Single-Screws and Twin-Screws ....... 183
  - 20.3.8 Tool/Die .................................................. 184
  - 20.3.9 Calibration ................................................ 184
  - 20.3.10 Corrugation ............................................. 185
  - 20.3.11 Cooling .................................................. 185
  - 20.3.12 Feeding .................................................. 186
  - 20.3.13 Marking .................................................. 186
  - 20.3.14 Further Processing ...................................... 186
  - 20.3.15 Cutting .................................................. 187
  - 20.3.16 Winding .................................................. 188
- **20.4 Extrusion Processes** ....................................... 188
  - 20.4.1 Straight Extrusion ....................................... 189
  - 20.4.2 Extrusion with Angle Tool/Coating ................. 189
  - 20.4.3 Extrusion of Plates and Sheets ...................... 190
  - 20.4.4 Co-extrusion ............................................ 191
  - 20.4.5 Film Blowing ............................................ 191
    - 20.4.5.1 Advantages (+) and Limitations (−) .............. 192
  - 20.4.6 Cable Production ....................................... 193
  - 20.4.7 Monofilament ........................................... 194
  - 20.4.8 Compounding ............................................ 195
- **20.5 Design for Extrusion** ..................................... 196
  - 20.5.1 Ribbing – Stiffening .................................... 197
  - 20.5.2 Cavity .................................................. 197
  - 20.5.3 Sealing Lip ............................................. 197
  - 20.5.4 Hinge ................................................... 198
  - 20.5.5 Guide .................................................. 198
  - 20.5.6 Sliding Joint ........................................... 198
  - 20.5.7 Snap-Fit Joint ......................................... 199
  - 20.5.8 Bellow .................................................. 199
  - 20.5.9 Insert/Reinforcement ................................... 199
  - 20.5.10 Friction Surface ....................................... 200
20.5.11 Printing/Stamping ........................................ 200
20.5.12 Decoration Surface ........................................ 200
20.5.13 Drilled Side Holes ........................................ 201
20.5.14 Irregular Holes ............................................... 201
20.5.15 Corrugation ................................................... 201
20.5.16 Spiral Forming ............................................... 202
20.5.17 Foaming ........................................................ 202
20.5.18 Extruded Screw Holes ..................................... 202
20.5.19 Muffing and Hot Plate Welding ......................... 203

CHAPTER 21 Alternative Processing Methods for Thermoplastics .......... 204
21.1 Blow Molding .................................................... 204
21.2 Rotational Molding .............................................. 206
21.3 Vacuum Forming ................................................ 207

CHAPTER 22 Material Selection Process ........................................ 209
22.1 How Do You Select the Right Material in Your Development Project? ........................................ 209
22.2 Development Cooperation ....................................... 210
22.3 Establishing the Requirement Specifications ................ 210
22.4 MUST Requirements ............................................ 211
22.5 WANT Requirements ........................................... 212
22.6 Specify and Sort the Material Candidates ................. 213
22.7 Make a Detailed Cost Analysis ................................ 214
22.8 Establish a Meaningful Test Program ......................... 215

CHAPTER 23 Requirements and Specification for Plastic Products .......... 216
23.1 Background Information ........................................ 216
23.2 Batch Size ........................................................ 217
23.3 Part Size ........................................................... 218
23.4 Tolerance Requirements ....................................... 218
23.5 Part Design ......................................................... 220
23.6 Assembly Requirements ....................................... 223
23.7 Mechanical Load ................................................. 223
23.8 Chemical Resistance ............................................ 224
23.9 Electrical Properties ............................................ 225
23.10 Environmental Impact ......................................... 226
23.11 Color ............................................................. 227
23.12 Surface Properties ............................................. 228
23.13 Other Properties ................................................. 230
23.14 Regulatory Requirements ..................................... 231
23.15 Recycling Requirements ..................................... 232
23.16 Cost Requirements ............................................. 233
## Contents

23.17 Requirement Specification – Checklist ........................................... 234
  23.17.1 Background information .......................................................... 234
  23.17.2 Batch Size ............................................................................. 234
  23.17.3 Part Size ................................................................................ 235
  23.17.4 Tolerance Requirements ........................................................... 235
  23.17.5 Part Design ............................................................................ 235
  23.17.6 Assembly Requirements ........................................................... 235
  23.17.7 Mechanical Load .................................................................... 235
  23.17.8 Chemical Resistance ................................................................. 235
  23.17.9 Electrical Properties ................................................................. 235
  23.17.10 Environmental Impact ............................................................. 236
  23.17.11 Color ................................................................................... 236
  23.17.12 Surface Properties ................................................................. 236
  23.17.13 Other Properties ................................................................... 236
  23.17.14 Regulatory Requirements ....................................................... 237
  23.17.15 Recycling ............................................................................. 237
  23.17.16 Costs .................................................................................... 237

---

### Design Rules for Thermoplastic Moldings ................................................. 238

#### CHAPTER 24

24.1 Rule 1 – Remember That Plastics Are Not Metals ................................ 239
24.2 Rule 2 – Consider the Specific Characteristics of Plastics .................... 240
  24.2.1 Anisotropic Behavior .................................................................. 241
  24.2.2 Temperature-Dependent Behavior ................................................. 241
  24.2.3 Time-Dependent Stress-Strain Curve ............................................ 242
    24.2.3.1 Creep ................................................................................. 242
    24.2.3.2 Relaxation .......................................................................... 242
  24.2.4 Speed-Dependent Characteristics ................................................ 243
  24.2.5 Environmentally Dependent Characteristics ................................ 244
  24.2.6 Easy to Design .......................................................................... 244
  24.2.7 Easy to Color ........................................................................... 244
  24.2.8 Easy to Assemble ...................................................................... 245
  24.2.9 Recycling ................................................................................ 245
24.3 Rule 3 – Design with Regard to Future Recycling ................................. 246
  24.3.1 Dismantling ............................................................................. 246
  24.3.2 Reused Materials .................................................................... 248
  24.3.3 Coding .................................................................................. 248
  24.3.4 Cleaning ................................................................................ 249
24.4 Rule 4 – Integrate Several Functions into One Component .................... 249
24.5 Rule 5 – Maintain an Even Wall Thickness .......................................... 251
24.6 Rule 6 – Avoid Sharp Corners ............................................................ 252
24.7 Rule 7 – Use Ribs to Increase Stiffness ................................................ 254
  24.7.1 Limitations when Designing Ribs ................................................... 254
  24.7.2 Material-Saving Design ............................................................... 255
  24.7.3 Avoid Sink Marks at Rib Joints ....................................................... 255

---

XIII
### Troubleshooting – Causes and Effects

#### CHAPTER 29

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>28.3.3</td>
<td>Brainstorming</td>
<td>308</td>
</tr>
<tr>
<td>28.3.4</td>
<td>Verification of Causes</td>
<td>308</td>
</tr>
<tr>
<td>28.3.5</td>
<td>Planning of Actions to Take</td>
<td>309</td>
</tr>
<tr>
<td>28.4</td>
<td>Statistical Design of Experiments – DOE</td>
<td>309</td>
</tr>
<tr>
<td>28.4.1</td>
<td>Factorial Experiments</td>
<td>310</td>
</tr>
<tr>
<td>28.5</td>
<td>Failure Mode Effect Analysis – FMEA</td>
<td>313</td>
</tr>
<tr>
<td>28.5.1</td>
<td>General Concepts of FMEA</td>
<td>314</td>
</tr>
<tr>
<td>29.1</td>
<td>Molding Problems</td>
<td>316</td>
</tr>
<tr>
<td>29.2</td>
<td>Fill Ratio</td>
<td>318</td>
</tr>
<tr>
<td>29.2.1</td>
<td>Short Shots – The Part Is Not Completely Filled</td>
<td>318</td>
</tr>
<tr>
<td>29.2.2</td>
<td>Flashes</td>
<td>319</td>
</tr>
<tr>
<td>29.2.3</td>
<td>Sink Marks</td>
<td>319</td>
</tr>
<tr>
<td>29.2.4</td>
<td>Voids or Pores</td>
<td>320</td>
</tr>
<tr>
<td>29.3</td>
<td>Surface Defects</td>
<td>321</td>
</tr>
<tr>
<td>29.3.1</td>
<td>Burn Marks</td>
<td>321</td>
</tr>
<tr>
<td>29.3.1.1</td>
<td>Discoloration, Dark Streaks, or Degradation</td>
<td>321</td>
</tr>
<tr>
<td>29.3.1.2</td>
<td>Black Specks</td>
<td>321</td>
</tr>
<tr>
<td>29.3.1.3</td>
<td>Splays or Silver Streaks (Partly over the Surface)</td>
<td>322</td>
</tr>
<tr>
<td>29.3.1.4</td>
<td>Diesel Effect – Entrapped Air</td>
<td>323</td>
</tr>
<tr>
<td>29.3.2</td>
<td>Splays or Silver Streaks (All over the Surface)</td>
<td>324</td>
</tr>
<tr>
<td>29.3.3</td>
<td>Surface Streaks – Bad Color Dispersion</td>
<td>324</td>
</tr>
<tr>
<td>29.3.4</td>
<td>Surface Streaks – Unfavorable Pigment Orientation</td>
<td>325</td>
</tr>
<tr>
<td>29.3.5</td>
<td>Surface Gloss – Matte/Shiny Surface Variations</td>
<td>325</td>
</tr>
<tr>
<td>29.3.6</td>
<td>Surface Gloss – Corona Effect</td>
<td>326</td>
</tr>
<tr>
<td>29.3.7</td>
<td>Splays, Stripes, and Blisters</td>
<td>326</td>
</tr>
<tr>
<td>29.3.8</td>
<td>Glass Fiber Streaks</td>
<td>327</td>
</tr>
<tr>
<td>29.3.9</td>
<td>Weld-Lines (Knit-Lines)</td>
<td>327</td>
</tr>
<tr>
<td>29.3.10</td>
<td>Jetting</td>
<td>328</td>
</tr>
<tr>
<td>29.3.11</td>
<td>Delamination</td>
<td>329</td>
</tr>
<tr>
<td>29.3.12</td>
<td>Record Grooves (Orange Peel)</td>
<td>329</td>
</tr>
<tr>
<td>29.3.13</td>
<td>Cold Slug</td>
<td>330</td>
</tr>
<tr>
<td>29.3.14</td>
<td>Ejector Pin Marks</td>
<td>330</td>
</tr>
<tr>
<td>29.3.15</td>
<td>Oil Stain – Brown or Black Specks</td>
<td>331</td>
</tr>
<tr>
<td>29.3.16</td>
<td>Water Stain</td>
<td>331</td>
</tr>
<tr>
<td>29.4</td>
<td>Poor Mechanical Strength</td>
<td>332</td>
</tr>
<tr>
<td>29.4.1</td>
<td>Bubbles or Voids inside the Part</td>
<td>332</td>
</tr>
<tr>
<td>29.4.2</td>
<td>Cracks</td>
<td>332</td>
</tr>
<tr>
<td>29.4.3</td>
<td>Unmelts (Also Called Pitting)</td>
<td>333</td>
</tr>
<tr>
<td>29.4.4</td>
<td>Britleness</td>
<td>334</td>
</tr>
<tr>
<td>29.4.5</td>
<td>Crazing</td>
<td>334</td>
</tr>
<tr>
<td>29.4.6</td>
<td>Problems with Regrind</td>
<td>335</td>
</tr>
</tbody>
</table>
29.5 Dimensional Problems ........................................ 335
  29.5.1 Incorrect Shrinkage ........................................ 335
  29.5.2 Unrealistic Tolerances .................................... 336
  29.5.3 Warpage .................................................... 337

29.6 Production Problems ........................................... 338
  29.6.1 Part Sticks in the Cavity ................................ 338
  29.6.2 Part Sticks on the Core .................................. 338
  29.6.3 Part Sticks on the Ejector Pins ......................... 339
  29.6.4 Sprue Sticks in the Mold ................................. 340
  29.6.5 Stringing .................................................. 341

CHAPTER 30 Statistical Process Control (SPC) ...................... 342
  30.1 Why SPC? ..................................................... 342
  30.2 Definitions in SPC .......................................... 343
    30.2.1 Normal Distribution (Gaussian Dispersion) ....... 343
  30.3 Standard Deviations ......................................... 343
    30.3.1 One Standard Deviation ................................. 343
    30.3.2 Six Standard Deviations (Six Sigma) ............... 344
    30.3.3 Control Limits .......................................... 344
    30.3.4 Target Value ............................................ 346
    30.3.5 Target Value Centering (TC) .......................... 347
    30.3.6 Capability Machine (Cm) .............................. 347
    30.3.7 Capability Machine Index (Cmk) ..................... 348
    30.3.8 Capability Process (Cp) ............................... 348
    30.3.9 Capability Process Index (Cpk) ...................... 349
    30.3.10 Six Important Factors ................................. 349
    30.3.11 Machine Capability .................................. 350
    30.3.12 Process Capability ................................... 350
  30.4 How SPC Works in Practice ................................. 351
    30.4.1 Software ................................................ 351
    30.4.2 Process Data Monitoring .............................. 352

CHAPTER 31 Internet Links ............................................. 354

Index ................................................................. 355
Foreword

For many years, I had the idea of writing a book about injection molding, as I have spent over 45 years of my working life on this subject.

When I retired in 2009 I was given great support by my friends Katarina Elner-Haglund and Peter Schulz of the Swedish plastics magazine Plastforum, who asked me to write a series of articles about thermoplastics and their processing for the magazine.

I was also hired at this time to work with educational programs at the Lund University of Technology, the Royal University of Technology in Stockholm, and a number of industrial companies in Sweden, as a result of which this book was developed.

My aim has been to write in such a way that this book can be understood by everyone, regardless of prior knowledge about plastics. The book has a practical approach with lots of pictures and is intended to be used in secondary schools, universities, industrial training, and self-study. In some of the chapters there are references to worksheets in Excel that can be downloaded free from my website: www.brucon.se.

In addition to the above-mentioned persons, I would like to extend a warm thanks to my wife Ingelöv, who has been very patient when I’ve been totally absent in the “wonderful world of plastics” and then proofread the book; my brother Hans-Peter, who has spent countless hours on adjustments of all the images etc; and my son-in-law Stefan Bruder, who has checked the contents of the book and contributed with many valuable comments.

I would also like to thank my previous employer, DuPont Performance Polymers and especially my friends and former managers Björn Hedlund and Stewart Daykin, who encouraged the development of my career as a trainer until I reached my ultimate goal and dream job of “global technical training manager”. They have also contributed with a lot of information and many valuable images in this book.

I also want said a big thank you to my friends and business partners in all educational programs in recent years, who have supported me and contributed with many valuable comments, information and images for this book, and a special thanks to those who have made this printing possible thanks to the ads in the beginning. The whole list would be very long but you will find some of them in the list of internet links in Chapter 31.

In this Second Edition:

This edition contains greatly expanded coverage of extrusion, collected into a new Chapter 20. There are also a number of new and updated figures, with numerous small improvements and corrections throughout the text. These are complemented by an all-new professional layout and structure, which I hope will help readers to navigate the book comfortably.
I would like to thank Mark Smith at Carl Hanser Verlag for all the support that I received during the last years with my book in various languages.

_Ulf Bruder_

Karlskrona, Sweden
3) LDPE is used for film blowing and extrusion.

A large part of all the polyethylene produced is used for film blowing. If the film is soft and flexible, it is either made of LDPE or LLDPE. If it has the rustle of the free bags at the grocery store, it is probably made of HDPE. LLDPE is also used to improve the strength of LDPE film.

4) PEX

Cross-linked polyethylene is mainly used in the extrusion of tubes. The cross-linking provides improved creep resistance and better high-temperature properties.

You can even copolymerize ethylene with polar monomers and get everything from viscous products (e.g. melting glue) to tough films and impact-resistant hard shells such as golf balls.

A common copolymer is EVA (ethylene-vinyl-acetate). By varying the concentration of vinyl acetate (VA) from 2.5 to 95%, you can control the properties and produce a range of different types of material. Increased VA content leads to higher transparency and toughness.

Adhesives, carpet underlay, cable insulation, carriers of color masterbatches, stretch film, and coating film for cardboard and paper are typical uses of EVA.
2.2 Polypropylene (PP)

**Chemical facts:**

PP has a simple structure and is made up, like PE, only of carbon and hydrogen. It also belongs to the category of plastics called olefins.

Polypropylene is made up of a chain of carbon atoms, where every other carbon atom is bonded to two hydrogen atoms and every other to a hydrogen atom and a methyl group. The monomer formula is:

\[
\text{H}_2\text{C} = \text{CH} \leq \text{CH}_3
\]

Graphically you describe polypropylene:

---

Polypropylene is a semi-crystalline commodity, denoted by—and commonly referred to as—PP. It is also known as “polypropylene.” It is the second-largest plastic on the market, after LDPE.

Polypropylene was discovered in 1954, almost simultaneously by two independent researchers Ziegler and Natta, who went on to share the Nobel Prize in 1963.

The Italian chemical company Montecatini launched the material on the market in 1957.

The polymerization of polypropylene can control both crystallinity and molecule size. One can also copolymerize polypropylene with other monomers (e.g. ethylene).

Polypropylene can occur as a homopolymer, random or block copolymer depending on the polymerization method. Polypropylene can also be mixed with elastomers (e.g. EPDM), filled with talc (chalk), or reinforced with glass fiber. In this way it is possible to obtain more grades with widely differing characteristics than can be achieved for any other plastic. Certain grades of polypropylene can handle a continuous temperature of 100 °C plus peaks of up to 140 °C and can therefore be classified as engineering plastics.
2.7.1 Properties of PMMA

+ Very high transparency (98%)
+ High rigidity and surface hardness
+ Very good UV resistance
+ Good optical properties
+ Can be used in implants

− High thermal expansion coefficient
− Scratch resistance
− Low resistance to stress-cracking
− Solvent resistance
− High melt viscosity (difficult to fill thin walls)

2.7.2 Recycling

PMMA can be easily recycled, and is denoted by the recycling code > PMMA <.

2.7.3 Application Areas

PMMA can be injection molded and extruded. Semi-finished products in PMMA can be processed with conventional machining. PMMA is superior to polycarbonate and polystyrene for laser marking.

Figure 2.27 PMMA works really well in reflective items.

Figure 2.28 PMMA is much used by the lighting industry, e.g. as a screen for fluorescent tubes.

Figure 2.29 Ophthalmic lenses. PMMA is highly compatible with the human body and is therefore used in implants. Due to its extremely good optical properties, PMMA is used in artificial lenses that are surgically inserted into the eye.

Figure 2.30 Safety glass at sports arenas. The protective glass shields around hockey rinks are usually made of PMMA as the material has high transparency and sufficient toughness.
3.1 Polyamide or Nylon

Polyamide is a semi-crystalline engineering plastic, denoted by PA. There are several different types of polyamide, of which PA6 and PA66 are the most common. Polyamide was the first engineering polymer launched on the market. It is also the largest in volume since it is widely used in the automotive industry.

Polyamide was invented by DuPont in the United States in 1934 and was first launched as a fiber in parachutes and women’s stockings under the trade name Nylon.

A few years later, the injection-molding grades were launched. Nylon became a general term; DuPont lost the trademark and currently markets its polyamides under the trade name Zytel. Ultramid from BASF, Durethan from Lanxess, and Akulon from DSM are some of the other famous trade names on the market.

3.1.1 Classification

The development of polyamide has focused on improving the high-temperature properties and reducing water absorption. This has led to a number of variants where in addition to PA6 and PA66 the following types should be mentioned: PA666, PA46, PA11, PA12, and PA612.

About a decade ago, aromatic “high performance” polyamides were introduced, usually known as PPA, which stands for polyphthalamide. The latest trend is “bio-polyamides” made from long-chain monomers, e.g. PA410, PA610, PA1010, PA10, PA11, and PA612.

---

**Chemical facts:**

Polyamide is available in a number of variations, labeled alpha-numerically, e.g. PA66, indicating the number of carbon atoms in the molecules that make up the monomer. PA6 is the most common type of polyamide and has the simplest structure:

\[
\left\{ \text{NH} - \text{C} - \text{(CH}_2\text{)}_6 \right\}_N
\]

PA66 has a monomer that consists of two different molecules wherein each molecule has six carbon atoms, as illustrated below:

\[
\left\{ \text{NH} - \text{(CH}_2\text{)}_6 - \text{NH} - \text{C} - \text{(CH}_2\text{)}_4 - \text{C} \right\}_N
\]

Amide group

Acid group
3.4.1 Properties of Polycarbonate

+ Crystal clear (light permeability 89%)
+ Very high impact strength (at low temperatures down to −40 °C)
+ High operating temperature (120 °C constant, and 145 °C short-term peak load)
+ Negligible moisture absorption and good dimensional stability
+ Lower mold shrinkage than most other plastics
+ Good electrical properties

+ Self-extinguishing V-2 and can be V-0 with additives
+ Food-approved grades available
− High tendency to stress-crack under constant load
− Solvent triggers cracking
− Degrades in water hotter than 60 °C, but can be machine washed

3.4.2 Recycling

Material recycling is preferable for PC, although incineration for energy extraction is also an option. The recycling code is > PC <.

3.4.3 Application Areas

Polycarbonate can be processed by injection molding and extrusion, both with and without glass fiber. PC sheets can be vacuum formed.

Figure 3.26 Polycarbonate has a poor chemical resistance, as can be seen from the cracks caused by vinegar in the salad bowl here.
3.4 Polycarbonate

Figure 3.27 Extruded tubes of glass fiber reinforced polycarbonate are both stiff and strong and can withstand tough impact, as the paddle in this picture shows.

Figure 3.28 The glass for car headlamps is made of polycarbonate and coated with a thin layer of siloxane to improve scratch resistance, UV protection, and protection against solvents.

Figure 3.29 Polycarbonate is both incredibly impact resistant and suitable for painting, making it an excellent material for motorcycle helmets. The visor is also produced in polycarbonate.
Gas pipes and fittings for gas pipes can be made of PA11. This material is the first high-performance polyamide that has been approved to be used for pipes up to 100 mm (4 inches) in diameter at operating pressures up to 14 bars. This material may be biobased and contain 100% renewably sourced ingredients by weight.

Automotive radiator end tanks can be produced from PA610 bio-polyamide and resist the hot, chemically aggressive underhood environment. PA610 also has low water absorption. Some PA610 contains more than 40% renewably sourced ingredients by weight.

6.7 Biobased Polymers from Microorganisms

PHA (polyhydroxyalkanoate) is a linear semi-crystalline polyester produced by the bacterial fermentation of sugar, glucose, or lipids, i.e. a group of substances consisting of fats and fat-like substances. The material was developed by ICI in the 1980s, and there are very few producers in the market. The material has good weathering properties and low water permeability. Overall, it has properties similar to PP.
6.8 Bioethanol or Biomethanol

PE is a commodity that has begun to be produced again of renewable biobased raw materials.

In the 1970s, a substantial proportion of India’s ethanol was used for the manufacture of PE, PVC, and PS. In the 1980s, companies in Brazil began to manufacture biobased PE and PVC. However, when oil prices dropped in the early 1990s, production stopped. Twenty years later, production is beginning to build up again.

Today, the Brazilian company Braskem is a world leader in biobased PE. Commercial production started in September 2010, using sugar cane as a raw material to prepare bioethanol, which is then converted into ethylene, used in the production of PE. Total production is currently around 200,000 tons and represents 17% of the market for bioplastics.

Bio-PE is nonbiodegradable.

Other commodities that can come from renewable resources are PP and PVC.

Figure 6.12 PHA has many medical applications. PHA fibers can be used to suture wounds.

Figure 6.13 A plastic shopping bag produced in green Bio-PE.
This chapter describes the polymerization of thermoplastics and how to control their properties by using various additives.

Figure 8.1 95% of all the plastics produced are based on natural gas and oil. The remaining 5% comes from renewable sources, i.e. plants. In 2010 plastics accounted for about 4% of the total oil consumption, as follows:

- Heating 35%
- Transport 29%
- Energy 22%
- Plastic materials 4%
- Rubber materials 2%
- Chemicals and medicine 1%
- Other 7%

8.1 Polymerization

The polymerization of monomers obtained by cracking of oil or natural gas creates polymers (synthetic materials) that can be either plastic or rubber. The type of monomer determines which type of material you get, while the polymerization process itself can create different variations of the molecular chains, such as linear or branched as shown below.

Figure 8.2 Polymerization of ethylene can produce different variants of polyethylene. LLDPE is made up of linear chains like the one at the top of the figure. LDPE has a branched chain structure, as shown in the middle. And PEX has cross-linked chains, i.e. where there are molecular bonds between the chains, as shown at the bottom.
If a polymer is made up of a single monomer it is called a homopolymer. If there are more monomers in the chain it is called a copolymer. Acetal and polypropylene are resins that can occur in both these variations. The copolymer group (the second monomer) is mainly located after the main monomer in the chain. In the case of acetal there are about 40 main monomers between every copolymer group. The copolymer may also occur as a side branch in the main chain, in which case it is known as a graft copolymer.

An additional way to modify the polymer is to control where the different molecules end up in the chain (see next).

Figure 8.3 At the top we can see the linear chain of a pure polymer, such as polypropylene. By adding ethylene you get a polypropylene copolymer with a block structure according to the second chain from the top. This material has much better impact resistance than normal polypropylene.

By adding EPDM (rubber monomer) you get a graft polymer with a chain structure and a material with extremely high impact strength.

You can also create a copolymer by mixing the granules from different polymers. In this case, the material is known as an alloy or blend. ABS + PC is an example of this type of copolymer.

Figure 8.4 To a certain extent, we can control the properties of a polymer by influencing how a particular molecule in the chain is oriented. The red circles in the top two chains symbolize the –CH₃ group in polypropylene. If all the –CH₃ groups are oriented in the same direction, it is called isotactic.

In polypropylene, with the help of a so-called metallocene catalyst, you can orient the groups so that they are evenly distributed in different directions. In this case the chain is called syndiotactic.

In a material such as polystyrene, there is an aromatic molecule with 6 carbon atoms in a ring (symbolized by the red circle in the lower chain). This molecule ends up completely random both in orientation and distribution in the chain. Such a chain is called atactic.
In the tables below with values from the CAMPUS materials database (see next chapter) you will find HDT for a number of thermoplastics. NOTE! Some deviation from the values below may occur depending on the viscosity and additives of the materials.

<table>
<thead>
<tr>
<th>Type of polymer</th>
<th>HDT at 0.45 MPa</th>
<th>HDT at 1.8 MPa</th>
<th>Melting point</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS</td>
<td>100</td>
<td>90</td>
<td>–</td>
</tr>
<tr>
<td>Acetal copolymer</td>
<td>160</td>
<td>104</td>
<td>166</td>
</tr>
<tr>
<td>Acetal homopolymer</td>
<td>160</td>
<td>95</td>
<td>178</td>
</tr>
<tr>
<td>HDPE, polyethylene</td>
<td>75</td>
<td>44</td>
<td>130</td>
</tr>
<tr>
<td>PA 6</td>
<td>160</td>
<td>55</td>
<td>221</td>
</tr>
<tr>
<td>PA 6 + 30% glass fiber</td>
<td>220</td>
<td>205</td>
<td>220</td>
</tr>
<tr>
<td>PA 66</td>
<td>200</td>
<td>70</td>
<td>262</td>
</tr>
<tr>
<td>PA 66 + 30% glass fiber</td>
<td>250</td>
<td>260</td>
<td>263</td>
</tr>
<tr>
<td>Polyester PBT</td>
<td>180</td>
<td>60</td>
<td>225</td>
</tr>
<tr>
<td>PBT + 30% glass fiber</td>
<td>220</td>
<td>205</td>
<td>225</td>
</tr>
<tr>
<td>Polyester PET</td>
<td>75</td>
<td>70</td>
<td>255</td>
</tr>
<tr>
<td>PET + 30% glass fiber</td>
<td>245</td>
<td>224</td>
<td>252</td>
</tr>
<tr>
<td>PMMA (acrylic plastic)</td>
<td>120</td>
<td>110</td>
<td>–</td>
</tr>
<tr>
<td>Polycarbonate</td>
<td>138</td>
<td>125</td>
<td>–</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>90</td>
<td>80</td>
<td>–</td>
</tr>
<tr>
<td>PP, polypropylene</td>
<td>100</td>
<td>55</td>
<td>163</td>
</tr>
<tr>
<td>PP + 30% glass fiber</td>
<td>160</td>
<td>145</td>
<td>163</td>
</tr>
</tbody>
</table>

Note: The amorphous materials have no melting point.
9.4 Flammability Tests

The international testing institute Underwriters Laboratories has developed various tests to specify a material’s fire resistance. You select test bars with different thickness and ignite them either horizontally or vertically. We specify this as HB (= horizontal burning) or V-2, V-1, or V-0 (V = vertical burning). For a material to be classified as fire resistant, it must be extinguished by itself within a certain distance (HB) and at a certain time. When testing a material for V-0 to V-2 you will also give attention to possible drops that ignite cotton (see below).

9.4.1 HB Rating

![Figure 9.14](image)

Figure 9.14 The flame is applied for 30 seconds before the ignition speed is measured. HB classification is obtained if the ignition speed measured between two points does not exceed:
1. 40 mm/min for 3–13 mm test bars
2. 75 mm/min for test bars < 3 mm
3. If the flame goes out before the first mark

9.4.2 V Rating

![Figure 9.15](image)

Figure 9.15 When testing a test bar in a vertical position you will apply the flame twice during each 10 seconds. The contact time of the second ignition begins immediately after extinguishing the test bar of the first flame.
Most molders are using advanced computer-based software to calculate costs or post-costs of injection-molded parts. Unfortunately, it is very seldom that injection machine setters have insight into or get the opportunity to use such software, even though they have great potential to affect the costs by adjusting the injection-molding parameters.

How often does it happen that setters add a few seconds of extra cooling time when they have a temporary disturbance of the injection-molding cycle? And then forget to change back to the original settings before the parameters are saved for the next time the mold will be set up? Those extra seconds can mean thousands of Euros or Dollars in unnecessary production costs per year and may also reduce the company’s competitiveness.

The purpose of this chapter is to show how a fairly detailed cost calculation for injection-molded parts can be made. The setter also gets a tool that enables him/her to see how changes that are made in the process can influence the cost of the molded part. This tool is based on Microsoft Excel and is available for downloading at www.brucon.se. The user does not need any extensive knowledge of Excel in order to fill in the input values required to immediately obtain the final cost picture at the bottom of the page.

The rest of this chapter will explain how to use the Excel file and what the different input values mean.

When you open the file called Costcalculator.xls you must first make a copy of this file to your computer’s hard drive, otherwise the macro functions will not work. Depending on how the default values are set for your own Excel program, it may be necessary to make modifications of the security settings. Detailed information of how this is to be done can also be found on the author’s homepage. The Excel file is also in “read-only” mode, so it should be saved under a different name once you have completed it.
There are three different functions to choose between:

1. Read about the functions of this software
2. Compare the costs between two different materials
3. Make a full part cost calculation

Before you click on the key “I accept the conditions” you are only able to “Read about the functions of the software”. The two other keys will only display blank pages.

19.1 Part Cost Calculator

We will start with the “Part cost calculator”. This is the most advanced function, and we will go through all input values before we end the chapter with the “Material comparison calculator”.

In “Part cost calculator” you can make a relatively complete cost calculation for a single part, total delivery volume, or annual volume. When filling in the white input fields with blue text a quick way to get to the next field is to use the “Tab” key on your computer keyboard.

The final result is obtained at a given sales price but it is also possible to get the sales price using a predetermined profit that you wish to achieve.

![Part cost calculator screenshot](image)

**Figure 19.3** If you wish to practice with the same values that are shown above, just click on the key “Fill in an example” and the spreadsheet will automatically be filled with the values.
26.1 Molding Processing Analysis

In this chapter, we will go through the main injection-molding parameters that affect the quality of the moldings. We will also emphasize the value of working systematically and having good documentation.

Figure 26.1 shows a document called “Injection Moulding Process Analysis”. There is an Excel file that can be downloaded at www.brucon.se. On this sheet we can record most of the parameters that need to be documented to describe the injection-molding process for a molded part.

This document was designed by the author of this book when he was responsible for the technical service at one of the leading plastic suppliers in the Nordic region.

You may think: Why should I spend time to fill it in when I can get all the parameters printed out directly from the computer system in my molding machine? The answer is that you would probably drown in all the figures and only with difficulty find the cause of the problem. You would also have difficulties in finding the key parameters as the printouts from different machines are completely different.

This document is perfect for use both in problem solving and as a basis for process and cost optimization as well as for documenting a test drive or a start-up of a new job. If you fill in the document when the process is at its best you will have good benchmarks for comparison when there is a disturbance in the process. Therefore, we will closely examine the structure of this document and explain the meaning of the information in each input field. On the last page of this chapter, the document is presented in full-page format (Figure 26.48).
### INJECTION MOULDING PROCESS ANALYSIS

Please, use tab button when filling in this sheet

<table>
<thead>
<tr>
<th>Customer</th>
<th>Location</th>
<th>Date</th>
<th>Contact person</th>
<th>Phone no</th>
<th>Email</th>
</tr>
</thead>
</table>

#### Problem / Desire

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
</table>

#### Material

<table>
<thead>
<tr>
<th>Lot no</th>
<th>Masterbatch</th>
<th>MB content</th>
<th>%</th>
<th>Regrind</th>
<th>%</th>
</tr>
</thead>
</table>

#### Machine

<table>
<thead>
<tr>
<th>Screw type</th>
<th>Shut-off nozzle</th>
<th>Hold-pressure profile possible</th>
<th>Clamping force</th>
<th>kN</th>
</tr>
</thead>
</table>

#### Mould / part name

<table>
<thead>
<tr>
<th>Hot-runner system</th>
<th>No of cavities</th>
</tr>
</thead>
</table>

#### Wall thickness at gate

<table>
<thead>
<tr>
<th>Max. wall thickness</th>
<th>Min. wall thickn.</th>
</tr>
</thead>
</table>

#### Sprue dimension

<table>
<thead>
<tr>
<th>Runner dimension</th>
<th>Gate dimension</th>
</tr>
</thead>
</table>

#### Nozzle diameter

<table>
<thead>
<tr>
<th>Parts weight (sum)</th>
<th>Full shot weight</th>
</tr>
</thead>
</table>

#### Drying

<table>
<thead>
<tr>
<th>Hot air dryer...</th>
<th>Dehumidified dryer...</th>
<th>Direct transport of dried resin to hopper...</th>
</tr>
</thead>
</table>

#### Drying temp

<table>
<thead>
<tr>
<th>Drying temp</th>
<th>°C</th>
<th>Drying time</th>
<th>hours</th>
</tr>
</thead>
</table>

### Processing

#### Cylinder temp: Nozzle (front)

| °C | Zone 4 | °C | Zone 3 | °C | Zone 2 | °C | Zone 1 | °C |

#### Melt temperature

| °C | Mould temp. moving | °C | Mould temp. fixed | °C | Temp. checked by pyrometer |

#### Injection pressure

| MPa | Hold pressure | >>> Profile? <<< | MPa | Hold press. time | sec |

#### Injection speed

| >>> Profile? <<< | % | mm/sec | Fill time | sec |

#### Back pressure

| MPa | Screw rotation | RPM | Peripheral screw speed | Calculated | m/sec |

#### Dosing time

| sec | Cooling time | sec | Total cycle time | sec | Hold-up time | Calculated | min |

#### Dosing length

| mm | cm³ | Max. dosing length | mm | cm³ | Suck-back | mm | cm³ |

#### Hold pressure switch

| mm | Cushion | mm | Cushion stable |

#### Comments

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
</table>

---

**Figure 26.1** The working tool "Injection moulding process analysis", which is described in this chapter.
rotation speed compared to a less viscous standard grade. For example, impact-modified acetal with a melt index of 1–2 g/10 min has a recommended maximum peripheral speed of 0.2 m/s, compared to 0.3 m/s for a standard grade with melt index of 5–10 g/10 min. For glass fiber reinforced grades you will usually find the recommended maximum peripheral speed to be 30–50% of the speed for the unreinforced grade. Also, impact modified, flame retardant grades used to be more sensitive to shear than standard grades.

Having sufficiently high Hold pressure is especially important for semi-crystalline plastics. Usually it is recommended to have as high a pressure as possible without getting flashes in the parting line or having ejection problems. We provide hold pressures because many molders sometimes in good faith set far too low a hold pressure, resulting in poorer quality.

Other important parameters such as hold pressure time, hold pressure switch, back pressure, injection speed, and decompression are more dependent on the part design and machine conditions. We therefore cannot give any general values of these parameters, but refer you instead to Chapter 26.

Table 27.1 Typical processing data for unmodified standard grades of common thermoplastics.

<table>
<thead>
<tr>
<th>Semi-crystalline commodities</th>
<th>Material</th>
<th>Type</th>
<th>Melt temperature Nominal °C</th>
<th>Range °C</th>
<th>Mold temp. °C</th>
<th>Drying Temp. °C</th>
<th>Time Hours</th>
<th>Max moisture %</th>
<th>Dew point °C</th>
<th>Hold pressure MPa</th>
<th>Max peripheral speed m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyethylene PEHD</td>
<td>200</td>
<td>200–280</td>
<td>25–60</td>
<td>Does not normally need to be dried</td>
<td>25–35</td>
<td>1.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyethylene PELD</td>
<td>200</td>
<td>180–240</td>
<td>20–60</td>
<td>Does not normally need to be dried</td>
<td>25–35</td>
<td>0.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyethylene PELLD</td>
<td>200</td>
<td>180–240</td>
<td>20–60</td>
<td>Does not normally need to be dried</td>
<td>25–35</td>
<td>0.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyethylene PEMD</td>
<td>200</td>
<td>200–260</td>
<td>25–60</td>
<td>Does not normally need to be dried</td>
<td>25–35</td>
<td>1.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polypropylene PP</td>
<td>240</td>
<td>220–280</td>
<td>20–60</td>
<td>Does not normally need to be dried</td>
<td>35–45</td>
<td>1.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Amorphous commodities</th>
<th>Material</th>
<th>Type</th>
<th>Melt temperature Nominal °C</th>
<th>Range °C</th>
<th>Mold temp. °C</th>
<th>Drying Temp. °C</th>
<th>Time Hours</th>
<th>Max moisture %</th>
<th>Dew point °C</th>
<th>Hold pressure MPa</th>
<th>Max peripheral speed m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polystyrene PS</td>
<td>230</td>
<td>210–280</td>
<td>10–70</td>
<td>Does not normally need to be dried</td>
<td>45–50</td>
<td>0.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HIPS</td>
<td>230</td>
<td>220–270</td>
<td>30–70</td>
<td>Does not normally need to be dried</td>
<td>45–50</td>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAN</td>
<td>240</td>
<td>220–290</td>
<td>40–80</td>
<td>Does not normally need to be dried</td>
<td>45–50</td>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABS</td>
<td>240</td>
<td>220–280</td>
<td>40–80</td>
<td>80 3 0.1 −18</td>
<td>45–50</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASA</td>
<td>250</td>
<td>220–280</td>
<td>40–80</td>
<td>90 3–4 0.1 −18</td>
<td>40–45</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVC Soft</td>
<td>170</td>
<td>160–220</td>
<td>30–50</td>
<td>Does not normally need to be dried</td>
<td>40–45</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVC Hard</td>
<td>190</td>
<td>180–215</td>
<td>30–60</td>
<td>Does not normally need to be dried</td>
<td>50–55</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PMMA</td>
<td>230</td>
<td>190–260</td>
<td>30–80</td>
<td>8 4 0.05 −18</td>
<td>60–80</td>
<td>0.6</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
# Injection Molding Process Parameters

## Semi-crystalline engineering polymers

<table>
<thead>
<tr>
<th>Material</th>
<th>Type</th>
<th>Melt temperature Nominal</th>
<th>Melt temperature Range</th>
<th>Mold temp.</th>
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29.3.13 Cold Slug

Possible causes (listed in the most likely order):
1. The material freezes in the nozzle
2. None or incorrectly located cold slug pocket in the runner
3. The melt flows into the fixed half during the opening or closing phase of the injection-molding cycle

Suggested remedies (according to the causes above):
1. Increase the nozzle temperature
2. Locate the cold slug pocket opposite the sprue in the mold
3. Reduce the risk of melt leakage into the mold:
   - Increase the decompression (suck-back)
   - Reverse the injection unit during the opening and closing phase
   - Increase the injection speed

29.3.14 Ejector Pin Marks

Possible causes (listed in the most likely order):
1. The part sticks too tightly in the cavity
2. The part is not cold enough (stiff) at the ejection
3. Mold problems or a faulty design

Suggested remedies (according to the causes above):
1. Reduce the mold shrinkage:
   - Reduce the hold pressure
   - Reduce the hold pressure time
   - Increase the release agent (surface lubrication) in the resin
   - Use a release spray (initially)
2. Eject or cool the part more efficiently:
   - Increase or decrease the ejection speed
   - Reduce the mold temperature
   - Increase the hold pressure time or the cooling time
3. Workshop action required (see also Chapter 16):
   - Increase the draft angles in the cavity
   - Change the size or design of the ejector pins
29.3.15 Oil Stain – Brown or Black Specks

**Possible causes (listed in the most likely order):**

1. Leaking cooling fluid when an oil temperature control unit is used
2. Leaking hydraulic oil hoses (cores)
3. Lubrication drops from the mold
4. Contamination from the gripper of the robot
5. Micro-cracks in the walls or plates of the mold

**Suggested remedies (according to the causes above):**

1. Check hoses
2. Check hose connections
3. Clean the mold
4. Clean the gripper of the robot
5. *Workshop action required (see also Chapter 16):*
   - Repair the mold

29.3.16 Water Stain

**Possible causes (listed in the most likely order):**

1. Leaking temperature-control hoses in the mold
2. Leaking gaskets in the mold
3. Cracks in the plates of the mold

**Suggested remedies (according to the causes above):**

1. Check hose connections and hoses
2. Check O-rings and gaskets in the mold
3. *Workshop action required (see also Chapter 16):*
   - Repair the mold

---

*Figure 29.23* Here there are brown greasy oil stains on a white plastic cap.

*Figure 29.24* Here there is a diagonal mark on the surface that was formed when plastic melt came in contact with water in the cavity.
Index

A
ABS 18
acetal 26
acrylonitrile-butadiene-styrene 18
actual value 302
additive manufacturing 154
additives 78
amorphous 5
analytical troubleshooting 301
angle tool 189
anisotropic behavior 241
assembly methods 260
atactic 77
cooling systems 134
cooling time 292
corner radius 252
corrugation 185
cost calculations 168
creaks 332
crazing 334
creep 242
cushion 295
cylinder 180

D
dark streaks 321
decompression 294
degradation 321
delamination 329
design of experiments 309
design rules 238
deviation 302
diesel effect 323
dimensional problems 335
discoloration 321
dosing length 294
dosing time 292
draft angles 138
dry air dryer 279
drying 278

E
ejector pin marks 330
ejector systems 137
electrical properties 84, 96
environmental factors 70
EPS 15
extrusion 177

F
factorial experiments 310
family molds 126
feeding 186
fill ratio 318
film blowing 191
flame retardancy 86
flammability 95, 107
flashes 319
flexural modulus 91
fluoropolymers 47

G
gas injection 116
gate 131
gate location 256
glass fiber streaks 327
glass transition temperature 5
granulation methods 78

H
HB rating 95
HDPE 8
heat deflection temperature 86, 93
heat stabilization 85
high-performance thermoplastics 46
hinge 198
hold pressure 287
hold pressure switch 294
hold pressure time 287
hot air dryer 279
hot plate welding 265
hot runner systems 132
"hot stamp" printing 118
hygroscopic 278

I
impact strength 92
infrared spectrophotometer 108
infrared welding 266
injection-molding cycle 114
injection-molding machine 110
injection-molding methods 110
injection-molding process 270
injection pressure 286
injection speed 286, 289
injection unit 112
in-mold decoration 120
isotactic 77

J
jetting 328

L
laser marking 121
laser welding 266
LCP 50
LCPA 65
LDPE 8
liquid crystal polymer 50
LLDPE 8
locking unit 113

M
machine capability 350
masterbatch 80
material data 88
Material Data Center 98
material selection 209
MDPE 8
mechanical properties 79
melt index 97
melting point 5
melt temperature 282
metalizing 122
microtome analysis 109
mold 123
mold design 139
mold filling analysis 146
mold shrinkage 97, 284
molds with melt cores 128
monofilament 194
monomer 76
muffing 203
multi-component injection molding 115
multi-component molds 127

N
nonlinear 240
nozzle diameter 278
nylon 23

O
oil stain 331
orange peel 329

P
PA 23
painting 121
PBT 29
PC 33
PE 7
PEEK 53
PEI 54
peripheral speed 280, 291
PET 29
PEX 8
PHA 66
physical properties 80
PLA 64
plastic 1
PMMA 21
polyamide 23
polybutylene terephthalate 29
polycarbonate 33
polyester 29
polyether ether ketone 53
polyetherimide 54
polyethylene 7
polyethylene terephthalate 30
polylactide 64
polymer 1
polymerization 76
polymethyl methacrylate 21
polyoxymethylene 26
polyphenylene sulfide 52
polyphenylsulfone 57
polypropylene 11
polystyrene 15
polysulfone 56
polytetrafluoroethylene 47
polyvinylchloride 13
POM 26
poles 320
post-shrinkage 284
PP 11
PPA 48
PPS 52
PPSU 57
printing 117
problem analysis 306
process capability 350
processing data 298
process parameters 297
production problems 338
profile 196
prototype molds 145
PS 15
PSU 56
PTFE 47
PTT 65
PVC 13
pyrometer 282

Q
quality control 102

R
record grooves 329
recycling 73
regrind 335
reject 170
relaxation 242
replacement cost calculation 175
requirement specifications 210
ribs 254
riveting 268
rotating cores 125
rotational molding 206
rotational welding 264
runner systems 130

S
SAN 17
SBS 38
scanning electron microscope 108
screen printing 119
screw diameter 292
screw rotation 292
screw rotation speed 290
sealing lip 197
SEBS 38
semi-crystalline 5
service temperature 93
setpoint 302
<table>
<thead>
<tr>
<th>T</th>
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<tbody>
<tr>
<td>shrinkage</td>
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<td>silver streaks</td>
<td>322, 324</td>
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<td>181</td>
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<td>ultrasonic welding 262</td>
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