

José R. Lerma Valero

Plastics Injection Molding

Scientific Molding, Recommendations, and Best Practices



HANSER

Lerma Valero

Plastics Injection Molding



Bonus Download Material:

On our website you can download, together with the eBook Bonus, functional versions of the Excel worksheets described in the book:

<http://www.hanserpublications.com/ebookbonus>

José R. Lerma Valero

Plastics Injection Molding

Scientific Molding, Recommendations,
and Best Practices

Hanser Publishers, Munich

HANSER
Hanser Publications, Cincinnati

The Author:

José R. Lerma Valero, Cardedeu, Barcelona, Spain

Distributed in the Americas by:

Hanser Publications

414 Walnut Street, Cincinnati, OH 45202 USA

Phone: (800) 950-8977

www.hanserpublications.com

Distributed in all other countries by:

Carl Hanser Verlag

Postfach 86 04 20, 81631 Munich, Germany

Fax: +49 (89) 98 48 09

www.hanser-fachbuch.de

The use of general descriptive names, trademarks, etc., in this publication, even if the former are not especially identified, is not to be taken as a sign that such names, as understood by the Trade Marks and Merchandise Marks Act, may accordingly be used freely by anyone. While the advice and information in this book are believed to be true and accurate at the date of going to press, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

The final determination of the suitability of any information for the use contemplated for a given application remains the sole responsibility of the user.

Library of Congress Control Number: 2019953348

All rights reserved. No part of this book may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying or by any information storage and retrieval system, without permission in writing from the publisher.

© Carl Hanser Verlag, Munich 2020

Editor: Dr. Julia Diaz-Luque

Production Management: le-tex publishing services GmbH, Leipzig

Coverdesign: Max Kostopoulos

Typesetting: Kösel Media GmbH, Krugzell

Printed and bound by Hubert & Co. GmbH und Co. KG BuchPartner, Göttingen

Printed in Germany

ISBN 978-1-56990-689-7

E-Book ISBN 978-1-56990-690-3

Acknowledgments

Writing a book is a hard and demanding job; inevitably, on the way, even a long time before the decision of writing it, there are many moments and situations where help and support are needed and essential. For this reason, it is fair to thank people or entities that in different ways have collaborated or given me support to achieve this goal.

I have to start by thanking my awesome wife, Dolores, and my dear son, Kevin Lerma, for their understanding and enormous patience during this long “book time”. I apologize for the immense quantity of “family hours” that I have dedicated to this project. Thank you so much, dear Lola and Kevin.

To my parents, Ildefonso and Ana Maria, and my brother, Juan, who unfortunately cannot see this book but who for sure would be proud of it and its publication.

To Lidia Jimenez, my Customer Service Representative, for her support, complicity, patience, and encouragement during the long time of editing and adaptation of the original book and for her valuable opinion in the selection of the cover options. Thanks a lot, my “player”.

To Alejandro Alarcon, for his enthusiasm with the initial project of the book, for pushing and paddling in the right direction every day. Thanks a lot, my friend.

To Enric Garcia, General Manager of Biesterfeld Ibérica, for his support, his push in the decisive moments, and for his vision of the book project.

To Enric Albert, ex-General Manager of Biesterfeld Ibérica, for his detailed review of the initial draft, for his support, tips, and corrections on the original book.

To Albert Planas, the greatest cover designer that always surprises me with his proposals.

To the companies, owners, managers, collaborators, and teachers with whom I have worked and learned during this close to 40 years of profession in the plastics world.

To the attendees at my seminars, because from all of them I have learned.

To the Hanser team who collaborated on this edition, especially thanks to Julia Diaz-Luque, for her patience, constant improvements, and collaboration, and to Mark Smith for his interest and for following up on the project after our first contact at the K 2016 fair, and for believing in this book since the beginning.

To the original book sponsor companies, Biesterfeld, Coscollola (Krauss-Maffei), Helmut Roegele (Engel), Plasmatrete, Wittmann-Battenfeld, Zwick-Roell.

Finally, to the Biesterfeld Plastics company, for giving me the opportunity to have one of the most satisfying jobs in the world, having new challenges every day, learning from customers, suppliers, colleagues, and sharing every day knowledge with all of them.

José R. Lerma Valero

September 2019

Preface

This manual has been created thinking of plastics injection molding technicians as well as processing engineers and quality and design engineers.

The book was initially born as a small procedure guide for the company where I was working, for fine-tuning injection machines with the aim of creating a logical, safe, and optimized start-up method. Gradually, it grew and accumulated interesting information for the technicians, in my opinion, and it took shape until the final editing.

It was created for those who have ever needed a book to help and support them to understand the technology, materials, and thermoplastics injection process.

It is a book that helps identify the key points of the process and show, explore, and teach new tools to define more stable, robust, and consistent processes; a book with information, for example, such as the following:

- Clear explanations about the main key points of the thermoplastics injection molding process
- Glossaries with detailed explanations and easy-to-handle data tables
- Explanations about thermoplastics and their properties and behavior
- Support information to select material according to its further application
- Support information to determine the most suitable machine to use
- Real case examples, problems, analysis, and solutions
- Scientific injection molding explanations of tools, calculations, and portability
- Examples of defects and failures, their causes and possible solutions
- Easy and clear explanations for injection process optimization
- General processing recommendations

I hope that this book can be a tool for consulting and support during the professional life of the reader.

I also aim to encourage technicians toward a cultural change in both the analysis of problems and the parameterization and definition of robust plastics injection molding processes, where the transition from the empirical method toward the scientific method can be made using appropriate methodologies.

José R. Lerma Valero

September 2019

About the Author

José R. Lerma Valero was born in Barcelona, Catalonia, in 1962; he is married and has a son. He obtained a superior degree in mechanics, with specialty in molds, and studied business management. He started his professional life as a trainee in a small injection molding factory.

José R. Lerma has dedicated close to 40 years of his professional life to the world of thermoplastics. Most of this professional life in plastics injection factories has been dedicated to producing parts for the automotive sector, producing both technical and aesthetic parts, painted, with chrome plating, etc. The functions and responsibilities he carried out in these injection plants have been of all kinds; for example, Processing Engineer, Technical Department Manager, Maintenance Manager, Production Manager, and Plant Manager.

Currently, and for almost 12 years, he is the Technical Manager for Spain and Portugal in Biesterfeld Ibérica SLU, leader in polymer distribution in Europe, with a portfolio of materials from the world's leading manufacturers.

José R. Lerma has been collaborating for more than 15 years with different technical centers in Spain as a leader of different seminars all related to plastics and the transformation of plastics, having trained hundreds of technicians in this technology.

In 2013 he published the book “Advanced Manual of Thermoplastics Transformation” in the Spanish language, with great success among plastics injection technicians.

It should also be noted that for six years he has developed and taught a specific seminar about scientific injection molding methodology in Spain, Portugal, and some Latin-American countries quite successfully.

All this accumulated background of experience in real day-to-day cases in factories as well as the training received and the experience of providing training in seminars to technicians is reflected and shared in this book.



Contents

Acknowledgments	V	
Preface	VII	
About the Author	IX	
Part 1: Plastics		
Polymers	3	CHAPTER 1
1.1 Plastics	3	
1.2 Molecular Bonds	4	
1.3 Functionality	6	
1.4 Polymerization	6	
1.4.1 Polycondensation	6	
1.4.2 Polyaddition	6	
1.5 Determination of the Molecular Weight of Polymers	7	
1.6 Thermoplastics	8	
1.6.1 Classification of Thermoplastics	8	
1.6.1.1 According to Their Molecular Structure: Morphology	8	
1.6.1.2 According to Their Molecular Chain Form	11	
1.6.1.3 According to the Position of Atoms in the Chain	12	
1.7 Properties and Characteristics of Plastics	13	
1.7.1 Thermal and Physical Behavior	13	
1.7.1.1 Rheology	13	
1.7.1.2 Elastic Deformation	13	
1.7.1.3 Viscosity	13	
1.7.1.4 Glass Transition Temperature (T_g)	15	
1.7.1.5 Melting Temperature (T_m)	16	
1.7.1.6 Thermoplastics Behavior	17	
1.7.1.7 Changes of State in Amorphous Materials	17	
1.7.1.8 Changes of State in Semi-crystalline Materials	18	
1.7.1.9 Behavior under Load	19	
1.8 A Brief History of Plastics	21	
1.8.1 1900–1930	22	
1.8.2 1950s	23	
1.8.3 1960s	24	
Thermodynamic Behavior of Plastics: PVT Graphs	25	CHAPTER 2
2.1 Thermodynamics	25	
2.2 PVT Graphs	25	
2.2.1 PVT Graphs Related to Amorphous and Crystalline Materials	25	

	2.2.1.1	Dosage Stage, Plastification, Melting	26
	2.2.1.2	Injection Stage, Filling the Mold or Cavities . . .	26
	2.2.1.3	Hold Pressure Stage	27
	2.2.1.4	Cooling Stage	27
	2.2.1.5	Influence of Injection Molding Parameters Reflected in PVT Graphs	30
	2.2.1.6	Crystallization Stages	33
CHAPTER 3	Burn Test		35
3.1	Identification of Various Types of Plastics		35
3.2	Recognition and Identification of Plastics by Burn Test		36
CHAPTER 4	Water and Plastics, a Difficult Friendship		37
4.1	Exposure on Duty		37
4.2	Water and Polymer in Molten State		38
4.3	Water-Sensitive Plastics		38
CHAPTER 5	Acronyms for Some Plastics, Reinforced Plastics, and Rubbers		41
CHAPTER 6	General Features of Some of the Most Used Thermoplastics		46
6.1	Polyolefins		46
6.1.1	Polyethylene (PE)		46
6.1.1.1	High Density Polyethylene (HDPE)		46
6.1.1.2	Low Density Polyethylene (LDPE)		46
6.1.1.3	Linear Low Density Polyethylene (LLDPE)		47
6.1.1.4	Comparison of Different Structures of Polyethylenes		48
6.1.2	Polypropylene (PP)		49
6.1.2.1	PP Homopolymer Properties		49
6.1.2.2	PP Copolymers		49
6.1.3	Ethylene Vinyl Acetate (EVA)		50
6.1.4	Ethylene Vinyl Alcohol (EVOH)		50
6.2	Polyoxymethylene (POM)		50
6.3	Polystyrenes (PS)		51
6.3.1	PS General Purpose		51
6.3.2	Medium or High Impact PS (HIPS)		52
6.4	Acrylonitrile Butadiene Styrene (ABS)		52
6.5	Blend ABS-PC		53
6.6	Styrene Acrylonitrile (SAN)		53
6.7	Acrylonitrile Styrene Acrylic Rubber (ASA)		54
6.8	Polyamides (PA)		54
6.9	Polyesters		56
6.9.1	Polybutylene Terephthalate (PBT)		56
6.9.2	Polyethylene Terephthalate (PET)		56

6.10	Polyphenylene Oxide (PPO)	57
6.11	Polycarbonate (PC)	58
6.12	Polymethylmethacrylate (PMMA)	58
6.13	Liquid Crystal Polymer (LCP)	59
6.14	Elastomers	59
6.14.1	Thermoplastic Elastomer (TPE-V)	59
6.14.2	Elastomer Thermoplastic Vulcanized (ETPV)	60
6.14.3	Thermoplastic Copolymer Elastomer Ether Ester (TPC ET)	60
6.14.4	Polyurethane (TPU)	61
6.14.4.1	Composition	61
6.15	Styrene Butadiene Copolymer (SBC)	62
6.16	Ionomer	63
6.17	Polyphenylene Sulfide (PPS)	63
6.17.1	Properties	63
6.17.2	Features	64
6.18	Polysulfones	64
6.18.1	Polyphenyl Sulfone (PPSU)	64
6.18.2	Polyethersulfone (PESU)	64
6.18.3	Polysulfone (PSU)	65

Chemical Resistances 66

7.1	Chemical Substances	66
7.1.1	Ethers	66
7.1.2	Alkalis	67
7.1.3	Esters	67
7.1.4	Ketones	68
7.1.5	Aliphatic Compounds	69
7.1.6	Halogenated Hydrocarbons	69
7.1.7	Halogenated Compounds	69
7.1.8	Amines	69
7.1.9	Other Chemicals that May Attack Plastics	70

Additives 74

8.1	Stabilizers	74
8.2	Lubricants	75
8.3	Antioxidants	76
8.4	UV Protection	76
8.4.1	Absorbents	76
8.4.2	HALS	76
8.5	Plasticizers	76
8.6	Antistatic Compounds	77
8.7	Flame Retardants	77
8.7.1	Combustion Mechanism of a Plastic	78
8.7.1.1	Solid Phase	78

CHAPTER 7

CHAPTER 8

8.7.1.2	Gaseous Phase	78
8.7.2	Some Types of Flame Retardants	79
8.8	Halogen-Free Flame Retardants	79
8.8.1	Halogens	79
8.8.2	Usual Names for Halogen-Free Materials	80
8.8.3	Contribution of Halogens in Plastics	80
8.8.4	Need for Alternatives to Halogenated Materials	80
8.9	Foaming Agents	81
8.10	Hydrolysis Stabilizers	81
8.11	Slips and Antiblocking	81
8.11.1	Slips	81
8.11.2	Antiblocking	81
8.12	Nucleating Agents	81
8.13	Compatibility Agents	82
8.14	Impact Modifiers	82
8.15	Fillers and Reinforcements	82
8.16	Mineral Additives	83
8.17	Antifriction Lubricants	84
8.18	Dyes and Pigments	84
8.19	Masterbatch	85
8.20	Applications	87
8.20.1	Action Mode	87
8.20.2	Addition Mode	87
8.20.3	Some Products	87
CHAPTER 9	Tests on Plastics	88
9.1	Mechanical Tests	88
9.1.1	Tensile Test ISO 527 1-2	88
9.1.2	Flexural Test ISO 178	89
9.1.3	Wear Resistance Test TABER ASTM D1044	90
9.1.4	Hardness Tests	90
9.1.4.1	Ball Pressure Hardness Test ISO 2039-1	90
9.1.4.2	Rockwell Hardness Test ISO 2039-2	90
9.1.4.3	Shore A and Shore D Hardness Test ISO 868 ..	91
9.1.5	Impact Charpy Test ISO 179 IZOD, ISO 180	92
9.1.5.1	Izod Test ISO 180	92
9.1.5.2	Charpy Test ISO 179	93
9.1.6	Scratch ASTM D3363	93
9.1.7	Compression Set Test	94
9.2	Thermal Tests	94
9.2.1	Definitions	94
9.2.2	Vicat Test ISO 306	95
9.2.3	HDT ISO 75	95
9.2.4	Hot Ball Pressure Test	96
9.2.5	Relative Temperature Index (RTI) Test	96

9.2.6	Coefficient of Linear Thermal Expansion (CLTE) Test	97
9.2.7	Flammability Test UL94	97
9.2.8	Limited Oxygen Index (LOI) Test ISO 4589 1.2	99
9.2.9	Incandescent Glow Wire IEC 60695-2-13 and 2-12	100
9.2.10	Glow Wire Ignition Test (GWIT) IEC 60695-2-13, 2-12 . . .	101
9.2.11	Glow Wire Flammability Test (GWFT) IEC 60695-2-12 . . .	101
9.2.12	Reaction to Fire: Classification	101
9.3	Electric Tests	102
9.3.1	Dielectric Strength ASTM D149 IEC 60243-1	102
9.3.2	Dissipation Factor ASTM D150 IEC 60250	102
9.3.3	Dielectric Constant ASTM D150 IEC 60250	102
9.3.4	Comparative Tracking Index (CTI) IEC 60112	102
9.3.5	Surface Resistivity (SR) ASTM D527 IEC 6009 3	103
9.3.6	Volume Resistivity (VR) ASTM D527 IEC 6009 3	104
9.4	Rheological Tests	104
9.4.1	Melt Flow Rate (MFR), MFI ISO 1133	104
9.4.2	MVI and MVR	105
9.5	Weathering	105
9.5.1	XW Weather-Ometer	106
9.5.1.1	Accelerated Weathering	106
9.5.1.2	Tests in Natural Environments	107
9.5.2	Radiation	107
9.6	Stress in Transparent Materials	108
9.6.1	Residual Stress Measurement in Transparent Materials .	108
9.6.2	Method	108
9.7	Colors: <i>Lab</i> System	109
9.8	Chemical Resistance and Stress Cracking	110
9.8.1	Electrical Properties	110
9.8.1.1	HWI: Hot Wire Ignition	110
9.8.1.2	HAI: High Ampere Arc Ignition	111
9.8.1.3	Time of Arc Resistance (TAR) ASTM D 495	111
9.8.1.4	HVAR: High Voltage Arc Resistance to Ignition	111
9.8.1.5	HVTR: High Voltage Arc Tracking Rate	111
9.8.1.6	CTI: Comparative Tracking Index	112
9.8.1.7	RTI: Relative Temperature Index	112

Properties of Plastics: Understanding Technical Data Sheets 113

CHAPTER 10

10.1	Density	114
10.2	Bulk Density	115
10.3	Flow Rates	115
10.3.1	Melt Volume Index (MVI)	115
10.3.2	Melt Flow Index (MFI)	116
10.4	Tensile Stress, Mechanical Resistance	117
10.5	Elastic Modulus and Tensile Modulus	118
10.6	Impact Resistance	119
10.7	Coefficient of Linear Thermal Expansion (CLTE)	120

Part 2: Material Selection		
CHAPTER 11	Material Selection Checklist	129
	11.1 Technical Specifications	130
	11.2 Target Factor Values	131
CHAPTER 12	Material Selection	134

13.3.5	Screw	176
13.4	Hardening Treatments for Injection Unit	176
13.5	The Pressure Multiplier	176

Key Parameters for Setting the Injection Molding Process ... 178 **CHAPTER 14**

14.1	Injection Speed	178
14.2	Ideal Filling Situation	179
14.2.1	Filling Speed Rate	182
14.2.1.1	Very High Speeds	182
14.2.1.2	Very Low Speeds	182
14.2.1.3	What Affects the Filling Speed?	182
14.3	Melt Temperature	184
14.4	Screw Peripheral Speed	185
14.5	Back Pressure	186
14.6	Injection Pressure	187
14.6.1	Holding Pressure Switching Systems	188
14.7	Holding Pressure	188
14.8	Holding Pressure Time	189
14.8.1	Cavity Pressure Drop	189
14.8.2	Injected Mass Weight Control	189
14.9	Mold Temperature	190
14.10	Dosage	192
14.11	Cushion	192

Correct and Optimized Methodology for the Process Start-up 193 **CHAPTER 15**

15.1	Requirements: Information Required	193
15.1.1	Material	193
15.1.2	Part	193
15.1.3	Mold	193
15.1.4	Machine	193
15.2	Possible Previous Calculations	194
15.3	Injection Machines Tune-up	196
15.3.1	Motion Setting	197
15.3.2	Injection Machine Start-up	198
15.3.2.1	Injection Fine-Tuning	198
15.3.3	Operative Method	201
15.3.4	Progressive Mold Filling	202
15.3.4.1	Progressive Filling Pressure Graphs	203
15.3.4.2	Hold Pressure Stage	203
15.3.5	Key Parameters of Process Control	204
15.3.6	Start-up and Fine-Tuning of Injection Machines— Interpreting Graphs	205
15.3.6.1	Injection and Cavity Pressures	205
15.3.6.2	Effect of Parameters	205
15.3.6.3	Cavity Pressure	206

15.3.7	Effects of the Different Parameters	206
15.3.7.1	Mold Temperature	206
15.3.7.2	Melt Temperature	206
15.3.7.3	Part Temperature	207
15.3.7.4	Dosage Stroke	207
15.3.7.5	Back Pressure	207
15.3.7.6	Injection Speed	207
15.3.7.7	Holding Pressure	207
15.3.7.8	Material Viscosity	208
CHAPTER 16	Generic Recommendations for Injection Molding Conditions	209
CHAPTER 17	Mold Design Guide Recommendations	218
17.1	Metals Versus Steels for Molds	218
17.2	Runners	220
17.3	Types of Gates	224
17.3.1	Most Common Gates	224
17.4	Mold Cooling	226
17.5	Cooling System in Cores	226
17.6	Venting	227
17.6.1	Deep	227
17.6.2	Venting for Runners	228
17.6.3	Venting in Distribution Channels	229
17.6.4	Venting in Ejectors	229
17.7	Draft Angles	230
17.8	Shrinkage	230
CHAPTER 18	Gates: Types and Recommendations	231
18.1	Fan Edge	231
18.2	Submarine or Tunnel Gate	232
18.3	Pin Point Gate	232
18.4	Tab Gate	233
18.5	Sprue Gate or Direct Gate	234
18.6	Flash Gate	234
18.7	Outer Ring	235
18.8	Inner Ring	235
18.9	Overlapped Jump Gate	236
18.10	Pin Gate	236
18.11	Most Common Injection Points	237
18.12	Central Flow Distribution Channels	238
CHAPTER 19	Plastic Parts Design: Recommendations	239
19.1	Recommendations	239
19.1.1	Ribs and Reinforcements Designs	239

19.1.1.1	Relative Torsion Resistance vs Reference	240	
19.1.1.2	Deformation at Constant Load	241	
19.1.2	Tensile Stresses	241	
19.1.3	Thickness Design	242	
19.1.3.1	Changes in Thickness	243	
19.1.3.2	Homogeneous Thicknesses	243	
19.1.4	Sharp Corners and Radii	244	
19.1.5	Influence of the Notches in the Impact Resistance	245	
19.1.6	Slots and Undercuts	246	
19.1.7	Snap-Fit	247	
19.1.8	Rigidity	248	
19.1.9	Creep and Relaxation	248	
19.1.10	Tubular Frames, Screw Holes	249	
Injection: Some Practical Tips		250	CHAPTER 20
20.1	Inspection of Runners and Gates Systems	250	
20.1.1	Gate Depth, Width, and Length	250	
20.1.1.1	Defects Due to the Gates	251	
20.1.2	Gates and Runners Design	252	
20.1.3	Spiral Effect or Flow Distribution	253	
20.1.4	Nozzles in Processes with Hot Runners	254	
20.1.5	Cooling	254	
20.1.6	Purging or Cleaning of the Injection Unit	255	
20.1.7	Venting	255	
20.1.8	POM Foaming Test	257	
20.1.9	Surface Tension	258	
20.1.9.1	Contact Angle	259	
20.1.9.2	Industrial Methods for Activating the Surface or Increasing Surface Tension	260	
Part 4: Scientific Molding			
Scientific Molding or Injection by Advanced Methods		263	CHAPTER 21
21.1	Knowledge and Training are Tools for the Future	263	
21.2	The Process	263	
21.3	Some Concepts Related to Scientific Molding	264	
21.3.1	Molding Processor	264	
21.3.2	Science	264	
21.3.3	Intelligence	264	
21.4	Machine Inputs vs Process Outputs	265	
21.5	New Processing Tools	267	
21.6	Advanced Methods—Scientific Injection Molding Tools	269	
21.6.1	Relative Viscosity Analysis or In-Mold Rheology Test	269	
21.6.2	Delta P: Determination Method	274	
21.6.3	Process Window: Determination Method (for Holding Injection Pressure Phase)	276	
21.6.4	Gate Seal Study	278	

21.6.5	Method and Analysis of Injection Pressure Losses along the Filling System	280
21.6.6	Machine Portability	282
21.6.7	Cavities Balance Study	283
21.6.8	Study of Shear Stress at the Gates	284
21.6.9	Blank Templates	287
21.6.9.1	Gate Seal Study, Blank Template	287
21.6.9.2	In-Mold Rheology, Blank Template	288
CHAPTER 22	Using Spreadsheets: Advanced Molding and Machine Portability	289
22.1	Thermoplastic Processing by Injection—Advanced Manual	289
	Part 5: Failure Analysis	
CHAPTER 23	Process Under Control, Failure Analysis	303
23.1	Points to Consider	303
23.1.1	Clamping Unit	303
23.1.2	Barrels	303
23.1.3	Screws	303
23.1.4	Nozzles	304
23.1.5	Refrigeration System, Temperature Control in the Mold and the Machine	304
23.1.6	Water Connection System in Molds	304
23.1.7	Dryers and Dehumidifiers	305
23.1.8	Grinders	306
23.1.9	Hot Runner	307
23.1.10	Thermoregulators	307
23.1.11	Appearance Criteria	307
23.1.12	Resin Handling	307
23.2	Failure Analysis, Checks, and Optimizations	309
23.2.1	Preliminary Investigation of Failures	309
23.2.2	Process Optimization	310
23.2.2.1	Radii	310
23.2.2.2	Cold Slug	310
23.2.2.3	Steps for Analysis of Problems Derived from Plastics Injection Molding Process	311
23.2.3	Trials Injection Molding Parameters Template	314
CHAPTER 24	Typical Problems in Plastics Injection	315
24.1	Lack of Drying or Dehumidification	315
24.1.1	Materials Drying	316
24.1.2	How to Properly Dehumidify	317
24.2	Filling System	317
24.2.1	Effects on the Quality of the Parts	318
24.2.2	Runners System Design	319
24.3	Proper Position of the Gate	319
24.3.1	Consequences of a Non-correct Gate Location	320

24.3.2	Recommendations for Correct Gate Location	320
24.4	Hold Pressure Time Too Short	321
24.4.1	Hold Pressure Stage	321
24.4.2	Hold Pressure Time Too Short	321
24.5	Inadequate Melt Temperature	322
24.5.1	Incorrect Melt Temperature	322
24.5.2	Signs of Incorrect Melt Temperature	322
24.5.3	Correct Melt Temperature	322
24.5.3.1	Melt Temperature Measurement	322
24.5.3.2	30/30 Melt Temperature Measuring Method ..	323
24.6	Correct Mold Temperature	323
24.6.1	Incorrect Mold Temperature	324
24.6.2	Recommendations to Properly Adjust the Mold Temperature	324
24.7	Residues on Mold Surface	325
24.7.1	Types of Deposits	325
24.7.2	Mold Care	326
24.8	Excessive Material Drying	327

Defects in Injection Molded Parts 328 CHAPTER 25

25.1	Defects in Parts Manufactured by Thermoplastics Injection Molding	328
25.1.1	Sink Marks or Uncompensated Shrinkage	328
25.1.2	Streaks	330
25.1.2.1	Streaks Caused by Burns	330
25.1.2.2	Streaks Caused by Moisture	330
25.1.2.3	Streaks Caused by Trapped Air	331
25.1.3	Weld Lines	332
25.1.4	Grooves, Vibrations, and Corona Effects	333
25.1.5	Gloss	333
25.1.6	Jetting	334
25.1.7	Spots and Markings near the Gate	335
25.1.8	Black Spots	335
25.1.8.1	Process	335
25.1.8.2	Machine	336
25.1.8.3	Polymer	336
25.1.9	Inhomogeneous Material	336
25.1.10	Blushes near the Gate	337
25.1.11	Bubbles	337
25.1.12	Cracking	337
25.1.13	Delamination	337
25.1.14	Splay, Silver Marks	337
25.1.15	Warpage	338
25.1.16	Stress Cracking, ESC	338
25.1.17	Surface Scratching	338
25.2	Defects in Injection Molding and Painted Parts	338
25.2.1	Holes and Craters	338

25.2.2	Trapped Air	338
25.2.3	Part Molded with Stress	339
25.2.4	Cracks	339
25.2.5	Irregularities	340
25.2.5.1	Sinkings	340
25.2.5.2	Peaks/Crawling	340
25.2.5.3	Lack of Adhesion	341
25.3	Cross Cut Test	341
25.4	Defects in Chrome Plating on Plastic Parts	342
25.4.1	Defects	343
25.4.2	Peaks, Spots, Bubbles	343
25.4.3	Blisters	343
25.4.4	Adhesion	344
CHAPTER 26	Analysis of Real Cases	345
26.1	Broken Support Brackets	345
26.1.1	Drying of Material	345
26.1.2	Filling System Review and Optimization	347
26.2	Pulleys that Do Not Work	349
26.2.1	Radii	349
26.2.2	Material Selection	350
26.3	Broken Gears	350
26.4	Unfilled PC Cover	351
26.5	Dimensional Instability in Parts	352
26.6	Insufficient Filling	355
26.7	Several Problems with Polycarbonate	356
26.7.1	A Plastic Chair Full of Problems	356
26.7.1.1	Concentric Circular, Dark Area around the Gate	356
26.7.1.2	Weld Lines in the Back Chair Grill	356
26.7.1.3	Marks in the Cavity Gate	357
26.7.1.4	Streaks	357
26.8	Support Breaks	357
26.9	Deformation of ABS Part	359
26.10	Bimetallic Effect	360
26.11	Hesitation Effect (Flow Stoppage)	361
26.12	Gloss Caused by the Glass Fiber Reinforcement	363
26.13	Pressure-Limited Process: Always a Mistake to Avoid	365
26.14	Streaks in Transparent Polycarbonate	367
26.14.1	Dehumidifying	367
26.14.2	Back Pressure	368
26.14.3	Suction	368
26.14.4	Gate	368
26.15	Polyamide Parts Cannot Withstand the Assembly Stress	369
26.15.1	Gates	371

26.16	Unbalanced Runners	372
26.17	Material Degradation	372
26.18	TPU: The Unknown Thermoplastic	373
26.18.1	What is TPU?	374
26.18.1.1	Dehumidification	374
26.18.1.2	Back Pressure	375
26.18.1.3	Hold Pressure	375
26.18.1.4	Cooling and Total Time Cycle	376
26.19	Bubbles	376
26.19.1	Bubbles Caused by Trapped Air	377
26.19.2	Bubbles Caused by Vacuum	377
26.20	The Secret of the Night Shift Manager	378
26.20.1	Dryers and Dehumidifiers	379

Part 6: Reference Material

Reference Data Tables	383	CHAPTER 27
27.1 Maximum Residence Time	383	
27.2 Usual Mold Temperatures	383	
27.3 Shrinkage	384	
27.4 Drying Conditions	384	
27.5 Maximum Allowed Humidity Data	385	
27.6 Recommended Depth Venting Channels	386	
27.7 Mold and Melt Temperatures, Shear, and Other Properties	386	
27.8 Maximum Peripheral Speeds	387	
27.9 Density, Melt at Room Temperature	388	
Bibliography	389	CHAPTER 28
Glossary	390	CHAPTER 29
Disclaimer	394	
Index	395	

Part 1

Plastics

Polymers

Polymers are molecules very common in our environment. They may be natural or synthetic. We can find them in our food (starches, proteins), our clothing (cotton, polyester, silk, nylon, etc.), our homes (wood, paint), and even in our body (proteins, DNA). A polymer is a macromolecule with a high molecular weight. Its name comes from the Greek and we can roughly translate it as “many parts”.

Since polymers are substances with high molecular weight, they have a large size. This size is achieved by the repeated binding of small molecules called monomers. The binding is done in sequence: one unit after the other, like a chain where each unit is a link. The number of links (or monomers) indicates the degree of polymerization.

A common molecule (such as water) has a molecular weight of 18 grams/mol. This means that 6.06×10^{23} water molecules weigh 18 grams (1 mol). In the case of hexane, a solvent, it has a molecular weight of 86 g/mol. In comparison, for example, the molecular weight of UHMW PE (ultra high molecular weight polyethylene) can be 4,000,000 g/mol, or that of rubber can reach 1,000,000 g/mol. That is, 6.06×10^{23} rubber molecules weigh 1 ton. These data can give us an idea of the difference between small molecules and polymers.

Polymers have a heterogeneous molecular weight. When we speak of the molecular weight of polymers, we are talking about average amounts (see Section 1.5).

1.1 Plastics

All plastics are composed of large molecules bound together by strong link forces. All plastics are characterized by high molecular weights.

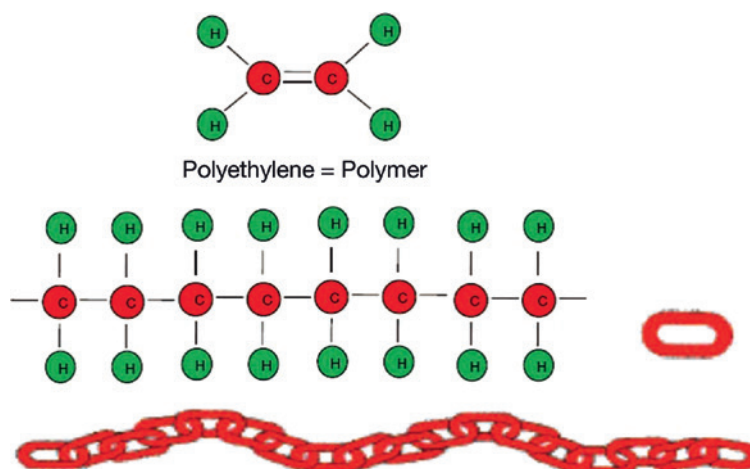
Plastics are obtained by polymerization. Through this process, a number of molecules or monomers are linked by reactions to produce a large molecule or polymer (macromolecule).

We can imagine a plastic like a ball of wool made up of many individual threads.

Monomers are chemical compounds in which the carbon atoms are linked by a double bond.



Figure 1.1 Example: ethylene monomer (molecule)



The carbon double bond ($C =$) allows the linking of molecules and the creation of polymers. The carbon atom is one of the few that can link itself through its double bonds.

When polymerized, these double bonds are broken and form bonds in two directions, forming the macromolecule. In the simplest cases they are joined one after the other like the links of a chain or a necklace.

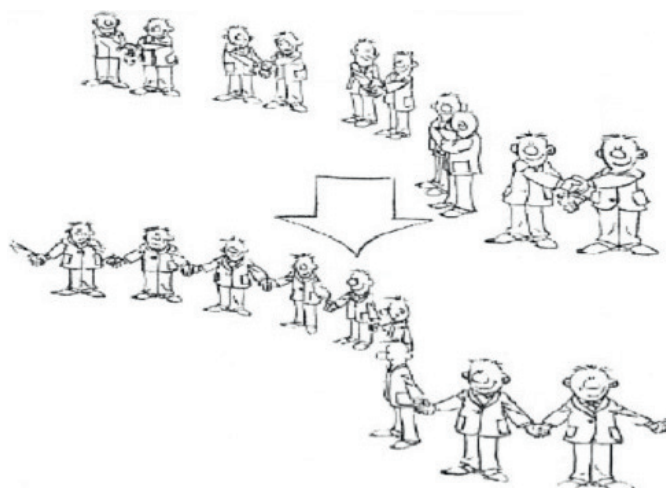
1.2 Molecular Bonds

Atoms of monomer molecules are linked by atomic bonds called covalent bonds. These bonds are forces holding two atoms together. Two atoms may be linked by single, double, or triple bonds.

Besides the bonding forces between atoms, there are bonding forces between molecules. These forces are called intermolecular forces. They attract the adjacent molecule with a certain intensity.

These forces provide and determine properties such as strength. To consider strength, we can use an analogous image: we can imagine a zipper, which provides strength to a fabric. The zipper hooks would be the intermolecular forces. Only if we pull very strongly do hooks come loose. However, these intermolecular forces are weaker than covalent bonding forces or atomic bonds.

Intermolecular forces are sensitive to the energy applied by heat. The higher the temperature, the more the molecules move; molecules begin to vibrate and intermolecular forces decrease. Above a certain temperature, those forces disappear and the molecules can move freely and easily slide against each other. However, the covalent bonds between atoms are much more resistant and their destruction requires much higher temperatures.

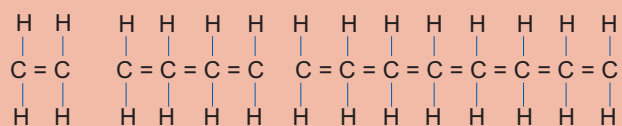


Unlike intermolecular bonds, if the heat energy is high enough, covalent bonds or bonds between atoms do not form again when the temperature decreases: the molecule remains destroyed.



Hydrocarbons

Hydrocarbons are **organic compounds** consisting only of **carbon** and **hydrogen** atoms. Their molecular structure consists of a framework of carbon atoms to which hydrogen atoms are attached.



■ C_2H_4 ethylene

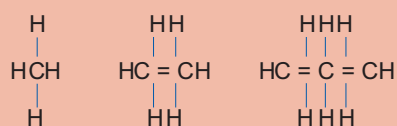
■ C_4H_8 butene

■ C_6H_{12} hexene

■ C_8H_{16} octene

Properties change depending on the molecular structure:

GAS \longrightarrow SEMI-SOLID



CH_4 C_2H_6 C_3H_8 ... C_4H_{10} ... C_5H_{12} ... $\text{C}_{16}\text{H}_{34}$
 METHANE ETHANE PROPANE ... BUTANE ... PENTANE ... PARAFFIN