



Extruding Plastics

Practical processing handbook

D.V. Rosato



CHAPMAN & HALL

Extruding Plastics

A practical processing handbook

D. V. Rosato

*Plastics Institute of America
Rhode Island School of Design
Chatham, MA, 02633
USA*



CHAPMAN & HALL

London · Glasgow · New York · Tokyo · Melbourne · Madras

**Published by Chapman & Hall, an imprint of Thomson Science,
2-6 Boundary Row, London SE1 8HN, UK**

Thomson Science, 2-6 Boundary Row, London SE1 8HN, UK

Thomson Science, 115 Fifth Avenue, New York, NY 10003, USA

Thomson Science, Suite 750, 400 Market Street, Philadelphia, PA 19106,
USA

Thomson Science, Pappelallee 3, 69469 Weinheim, Germany

Sold and distributed in North, Central and South America
by Kluwer Academic Publishers,
101 Philip Drive, Norwell, MA 02061, U.S.A.

In all other countries, sold and distributed
by Kluwer Academic Publishers Group.
P.O. Box 322, 3300 AH Dordrecht, The Netherlands.

First edition 1998

© 1998 Chapman & Hall

Thomson Science is a division of International Thomson Publishing **I(TP)**

Typeset in 10/12 Palatino by Best-set Typesetter Ltd., Hong Kong
Printed in Great Britain by The University Press; Cambridge

ISBN 0 412 82810 3

All rights reserved. No part of this publication may be reproduced,
stored in a retrieval system or transmitted in any form or by any means,
electronic, mechanical, photocopying, recording or otherwise, without
the prior written permission of the publishers. Applications for
permission should be addressed to the rights manager at the London
address of the publisher.

The publisher makes no representation, express or implied, with
regard to the accuracy of the information contained in this book and
cannot accept any legal responsibility or liability for any errors or
omissions that may be made.

A catalogue record for this book is available from the British Library

Extruding Plastics

Preface

Worldwide, extrusion lines successfully process more plastics into products than other processes by consuming at least 36 wt% of all plastics. They continue to find practical solutions for new products and/or problems to meet new product performances.

This book, with its practical industry reviews, is a unique handbook (the first of its kind) that covers over a thousand of the potential combinations of basic variables or problems with solutions that can occur from up-stream to down-stream equipment. Guidelines are provided for maximizing processing efficiency and operating at the lowest possible cost. It has been prepared with an awareness that its usefulness will depend greatly upon its simplicity and provision of essential information.

It should be useful to: (1) those already extruding and desiring to obtain additional information for their line and/or provide a means of reviewing other lines that can provide their line with operating improvements; (2) those processing or extruding plastics for the first time; (3) those considering going into another extrusion process; (4) those desiring additional information about employing the design of various products more efficiently, with respect to both performance and cost; (5) those contemplating entering the business of extrusion; (6) those in new venture groups, materials development, and/or market development; (7) those in disciplines such as nonplastics manufacturers, engineers, designers, quality control, financial, and management; and (8) those requiring a textbook on extrusion in trade schools and high schools or colleges.

Only a few theoretical concepts are included. Persons dealing with practicalities will find the theoretical explanations enlightening and understandable. Theorists will gain insight into the practical limitations of equipment, plastics, and people. There are various excellent books that provide detailed theoretical analysis; they are listed in the Reference section. However, this review of the industry's operating experiences presented with 387 figures and 128 tables will help make extrusion lines operate more efficiently and expand their capabilities. These experiences establish empirical analyses that, in turn, develop theoretical concepts.

The book's practical approach provides for the novice and experienced

personnel a description of extrusion advances and trends. This leads to 'streamlining' processing lines by anticipating and understanding problems that could occur, what causes them, how to eliminate them, and/or how to take corrective action. The content is arranged to provide a natural progression from simple to complex situations. It correlates materials, equipment, process controls, product requirements, and people. Thus, one learns how to avoid 'preventable' down-time and/or unacceptable products. A step-by-step approach is used to simplify and understand practical fundamentals that interrelate processes with plastics-to-products.

This comprehensive book explains in a clear, concise, simple format the different extrusion processes that produce many different commodity and engineered plastic products. Included are: (1) flexible-to-rigid-to-foam-to-decorative constructions; (2) both simple and complex shapes; (3) processing virgin and/or recycled plastics; (4) procedures for start-ups and shut-downs; (5) postforming in-line, troubleshooting, and so on. A target has been to open up new possibilities in the art of extruding, with the goal of approaching zero defect processing.

It is essential to re-emphasize what is reviewed in the text, namely that all data and information presented on equipment and plastics are to be used as guides. Obtain the latest, most complete, information from suppliers.

Information is derived from the author's experience as well as personal contacts with industry worldwide, including many industry people, and industry sources, as is evident by the references listed at the end of this book. Every possible care has been taken to ensure that the content of this book is correct. While the information contained is believed to be true and accurate, no one, including the editor, contributors, sources, and publisher, can accept any legal responsibility for any errors, omissions, operating risks/damages, or other factors. All information is provided in good faith but without legal responsibility. This book will serve to help people understand the process of extrusion and that includes maintaining the highest degree of safety and avoiding injury to personnel and damage to equipment.

Information contained in this book may be covered by US and world-wide patents. No authorization to utilize these patents is given or implied; they are discussed for information only. Disclosures are neither a license to operate nor a recommendation to infringe any patent. No attempt has been made to refer to patents by number, title, or ownership.

D. V. Rosato
Chatham, MA., USA
December, 1997

Contents

Preface	xiii
1 The complete extrusion process	1
Overview	1
Extruder type and construction	6
Extruder operation	10
Extrusion coating	13
Other lines	14
Processing plastic	19
Extruder heating and cooling profile	22
Auxiliary equipment	24
Plant operation	28
Plant safety	32
Acceptable risk	39
Energy conservation	40
Processor	42
Custom	43
Captive	43
Proprietary	43
Predicting performance	43
Scale-up	44
Myths and fact	44
People and productivity	46
Processing and patience	47
Troubleshooting	47
History	50
2 Extrusion machine and line	54
Features of extruder and production line	54
Overview	54

Single-screw extruder	56
Twin-screw extruder	60
Extruder components	65
Alignment	67
Borescoping	69
Drive system	70
Barrel	75
Barrel and feed unit	93
Auxiliary equipment	98
Operating extruder and complete line	116
Planning a line	118
Start-up and shut-down	121
Temperature/pressure and output	125
Maintenance	129
Troubleshooting	130
Training	142
Coextrusion	144
Melt flow characteristics	146
Types of construction	150
Selecting equipment	152
Safety	158
3 Processing plastic material	160
Overview	160
Plastic type	162
Properties	168
Heat profile	173
Melt flow and rheology	174
Melt flow and defect	178
Thermal properties	180
Purging	187
Recycling	188
Drying	190
4 Plasticizing screw process	199
Overview	199
Screw design	208
Output	210
Screw torque	212
Screw cooling	213
Performance	214
Mixing devices	216
Barrier screw	219
Melting action	220
Venting	221
Process performance	225

Wear	226
Screw inspection	226
5 Die design and performance	228
Overview	228
Melt behavior	241
Die land	242
Slit	246
Rod	246
Tear drop	246
Temperature	246
Manifold and die	250
Coextrusion dies	256
Special dies	266
Die design	270
Construction materials	273
Maintenance	275
Troubleshooting	276
6 Process control and computer	283
Overview	283
Trade-off	287
Sensors	290
Accuracy	296
Integration	301
Intelligent processing	304
7 Blown film	305
Overview	305
Plastic materials	312
Blown tube characteristics	315
Start-up	320
Orientation	323
Process optimization	324
Line control	325
Output rate	326
Die	334
Multi-layer or coextrusion	335
Film randomization	338
Troubleshooting	348
8 Flat film	349
Overview	349
Other type film	356
Flat or blown film	357
Plastic materials	358

Flat film characteristics	361
Start-up	362
Shut-down	362
Orientation	363
Process control	367
Line control	369
Output rate	369
Die	370
Troubleshooting	372
9 Sheet	376
Overview	376
Plastic materials	383
Processing ABS	383
Processing PET	386
Orientation	387
Process optimization	388
Line components	388
Roll stack	388
Coextruded or laminated sheets	396
Pull roll	400
Air knife	400
Trim and slitting	400
Antistatic bath	401
Process control	402
Cut-off	403
Winder	406
Die	409
Applications	411
Troubleshooting	412
10 Calendering	418
Overview	418
Calendering or extrusion	420
Calendering operation	422
Surface finishing	427
Plastic materials,	430
Fluxing and feeding	432
Heat sensitivity	433
Contamination	434
Recycling	434
Orientation	435
Processing optimization	435
Roll	435

Control	437
Application	437
Safety	438
Costing	438
Troubleshooting	440
11 Coating and lamination	441
Overview	441
Substrate	447
Plastic materials	448
Processing characteristics	449
Shut-down	456
Process optimization	457
Gauge variation	457
Neck-in	457
Substrate	459
Adhesion	460
Printing	462
Block and slip surface quality	463
Control	463
Dimensional stability	464
Heat sealing	464
Die	464
Applications	465
Safety	465
Troubleshooting	466
12 Wire and cable	469
Overview	469
Plastic materials	471
Processing characteristics	474
Other coating lines	478
Start-up	483
Process optimization	485
Die	486
Troubleshooting	493
13 Pipe and tube	494
Overview	494
Plastic materials	501
Processing characteristics	503
Process optimization	514
Orientation	518
Die	520

Applications	524
Cost	525
Troubleshooting	527
14 Profiles	528
Overview	528
Plastic materials	532
Processing characteristics	533
Coated profile substrate	535
Process optimization	536
Cooling profile	536
Window frame precision fast line	537
Rod	539
Robotic profile	540
Mechanical strength	540
Applications	541
Die	542
Troubleshooting	551
15 Blow molding	552
Overview	552
Plastic materials	554
Coextrusion	556
Processing characteristics	556
Extrusion blow molding	556
Injection blow molding	562
Stretch blow molding	570
Process optimization	574
Die/mold/tool	577
Applications	584
Cost	584
Troubleshooting	592
16 Fiber and filament	593
Overview	593
Plastic materials	595
Processing characteristics	596
Melt spinning	597
Dry spinning	598
Wet spinning	598
Other processes	599
Fiber twist	599
Filtration	600
Nonwoven	601

Spinneret	602
Process optimization	603
Theoretical versus actual value	604
Applications	606
Troubleshooting	606
17 Compounding	608
Overview	608
Plastic materials	609
Blend	615
Processing characteristics	616
Batch compounding	616
Continuous compounding	617
Feeder and blender	618
Reactive compounding	620
Pellet	622
Dicer	627
Type of mixer	628
Process optimization	628
Control	629
Die	629
Troubleshooting	629
18 Other processes	631
Introduction	631
Injection molding	631
Noncontinuous extruder	638
Continuous extruder	640
Mold	641
Injection-compression molding	642
Injection/blow molding with orientation	643
Continuous molding with extruder	645
Velcro strip Ferris wheel molding	645
Carousal molding	650
Thermoforming	650
Scrapless forming	661
Postforming	661
Netting	663
Foam	663
19 Testing and quality control	673
Introduction	673
Quality assurance	674
Testing	675

Type of test	677
Density and specific gravity	677
Melt index	680
Melt rheometer	682
Quality control	686
Statistical process control	687
Monitoring process variables	688
Assessing statistical practice	689
Quality system regulation	689
Extrusion variables	690
Plastic material	691
Melt flow	692
Process control	693
Product	695
Processing intelligence	696
Judgment and experience	696
Problem and solution	697
20 Summary	699
Introduction	699
Success by design	700
Cost	700
Estimating product cost	705
Direct and indirect cost	706
Technology cost modeling	707
Processing improvement	711
Process types	712
Plant control	719
Energy	720
Plastic and energy	721
People	725
Processing and patience	725
Plastics growth with extrusion	725
Appendices	732
Metric conversion charts	732
Standard metric symbols	735
Mathematical symbols and abbreviations	735
Greek alphabet	736
Properties of water	736
Angle conversions	736
References	737
Index	755

The complete extrusion process

OVERVIEW

The extrusion processes offer the advantages of complete versatile plastic processing techniques unsurpassed in economic importance by any other process. Worldwide, extruder lines are the largest converters of plastics and can be considered the most important production machinery in the plastic industry. Commercially, extrusion lines are targeted to give advantages with regard to operating cost (output per hour). The two main reasons that make them attractive to the processors and markets are their almost unlimited range of applications and their continuous production capabilities to meet new market challenges [1]. There are also batch or noncontinuous processing of plastics (Chapter 18) that include injection blow molding (Chapter 15), injection molding (Chapter 18), and the major market of compounding plastic materials (Chapter 17).

This book provides practical information that affects processing performances when changing individual variables during extrusion as well as on the important up-stream and down-stream equipment. The variables all relate to the common factors of temperatures, pressures, and times which, in turn, relate to the manufacturing output rates and costs. Each chapter in this book contains important information on different variables and the behavior of plastics during processing. Detailed information in one chapter that applies elsewhere will not be repeated in subsequent chapters. Thus, to gain the maximum benefit from this book, review or examine all chapters. The table of contents and index provide helpful cross references. Advantages and disadvantages as well as troubleshooting guides are provided throughout this book. The information presented comes from many worldwide industry sources, individuals and companies that include those listed in the Reference section at the end of this book.

All processes fit into an overall scheme that requires the interaction and

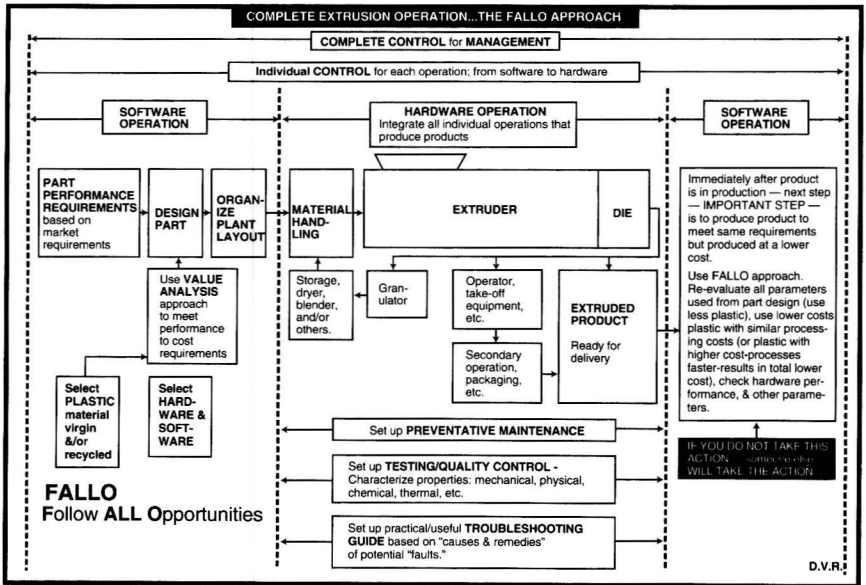


Figure 1.1 The FALLO approach.

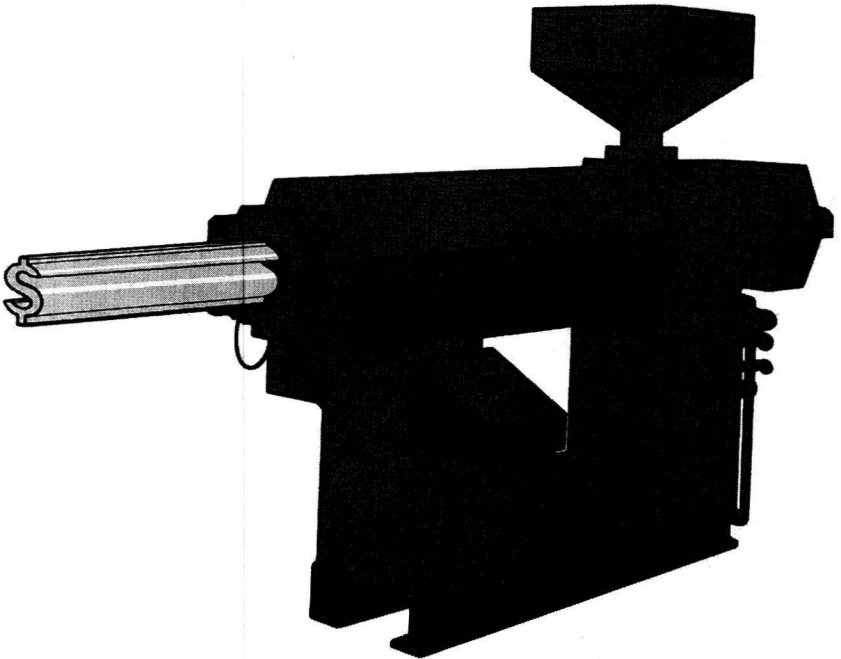


Figure 1.2 Extruders provide products used worldwide with profits.

proper control of different operations. An example is shown in Fig. 1.1 where the block diagram pertains to any process system. The FALLO (Follow ALL Opportunities) approach makes one aware that many steps are involved in processing and all must be properly understood and coordinated [1–6]. Basically the FALLO approach consists of: (1) designing a product to meet performance and manufacturing requirements at the lowest cost; (2) specifying the proper plastic material(s) that meet product performance requirements after being processed; (3) specifying the complete equipment line by (a) designing the die ‘around’ the product, (b) putting the ‘proper performing’ extruder ‘around’ the die, (c) setting up auxiliary equipment (up-stream to down-stream) to ‘match’ the operation of the complete line, and (d) setting up the required ‘complete controls’ (such as testing, quality control, troubleshooting, maintenance, data recording, etc.) to produce ‘zero defects;’ and (4) purchasing and properly warehousing plastic materials. Using this type of approach leads to maximizing the product’s profitability (Fig. 1.2).

Plastics, predominantly thermoplastics (TPs) (Chapter 3), are usually

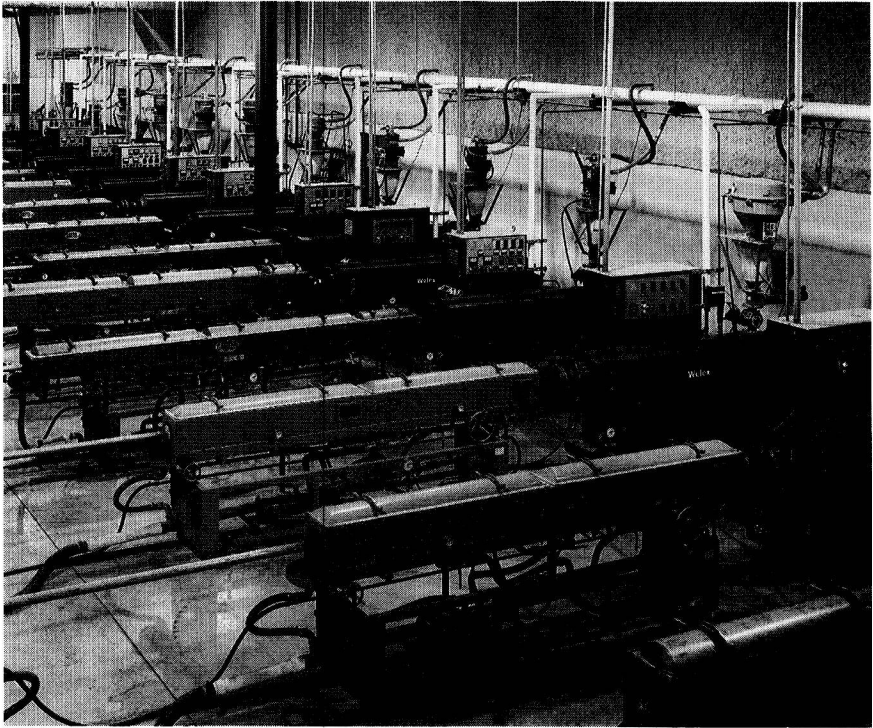


Figure 1.3 Double ‘H’ Plastics Co. with 14 complete pipe/profile lines with Welex extruders and Gonair/Gatto coolers.