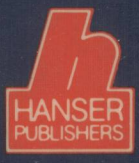
Walter Michaeli

Extrusion Dies

Design and Engineering Computations



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Foreword

The Society of Plastics Engineers is pleased to sponsor and endorse "Extrusion Dies for Polymers". This translation of the outstanding German volume fills a long standing void in the plastics technical literature published in English. The original volume in German has been cited worldwide as the first to cover this vital subject in the depth required by practicing extrusion engineers and technologists.

SPE, through its Technical Volumes Committee, has long sponsored books on various aspects of plastics and polymers. Its involvement has ranged from identification of needed volumes to recruitment of authors. An ever-present ingredient, however, is review of the final manuscript to insure accuracy of the technical content.

This technical competence pervades all SPE activities, not only in publication of books but also in other activities such as technical conferences and educational programs. In addition, the Society publishes four periodicals - *Plastics Engineering, Polymer Engineering and Science, Journal of Vinyl Technology* and *Polymer Composites* - as well as conference proceedings and other selected publications, all of which are subject to the same rigorous technical review procedure.

The resource of some 24,000 practicing plastics engineers has made SPE the largest organization of its type in plastics worldwide. Further information is available from the Society at 14 Fairfield Drive, Brookfield Center, Connecticut 06805.

Robert D. Forger
Executive Director
Society of Plastics Engineers

Preface

There are some fields of activity in polymer processing which have not yet been covered in a comprehensive way in one single book. Well, this happens once in a while, although it seems desirable to have the complex knowledge obtainable from many different sources combined in one textbook for the men in practise and for students. Such a field is the engineering and design of extrusion dies.

My former coworker - Dr. Walter Michaeli - has tried to do this job by writing this book and with it he has earned permission to teach "Extrusion Die Design" at the Aachen Technical University.

This book - which is now published in an English translation - is for the first time a unique and extensive representation of a very important subject in polymer processing; all the more considering that extrusion is still number one in plastics processing expressed in tonnage of material: More than 50 percent of all thermoplastics are extruded in one way or another; and there is definitely no indication that extrusion will lose this position.

This book gives the student a didactically well-guided introduction to a really complex subject; the book gives "those on the frontiers" - the practical men - the chance to supplement their knowledge and to compare their experiences with the given theoretical and process-analytical approaches and to use these to an increasing extent in future.

The approach to the subject "Extrusion Dies" is possible in different ways: via extrusion die theory or by studying the design and engineering of the dies.

The reader will learn that the computer is being used increasingly in extrusion die design. And we can even foresee today that the computation of very complex three-dimensional flow fields in profile dies and the description of elastic phenomena like swell processes will soon be accessible by using simple-to-handle data entering programs in combination with the finite-element-method (FEM); and this all with acceptable computing times and with the output of ready-to-use- and thus "practical" information. This field will stay in motion.

Nevertheless, sometimes it is necessary to mark a juncture, to collect the state of the art, and to get it down in a book.

This was done in this book. Perhaps, this book might turn out to be the book in extrusion die design.

Anyway, it deserves that reputation.

December 1983, Aachen, Germany

Professor Dr.-Ing. Georg Menges

Preface

In this book an attempt is made to present to the practitioner and to the student a broad picture of all extrusion tools for plastics. In pursuing that objective the various types of dies and their specific features will be discussed, guidelines for their design will be given and approaches to computational engineering analyses and their limitations will be demonstrated. That is even more important in view of the increasing efforts made by industry as well as academia, starting in the recent past and continuing in the presence, to model the transport phenomena (flow and heat transfer) in the extrusion die mathematically. These important projects are motivated primarily by the demand for higher productivity accompanied by better product quality (i.e. dimensional accuracy, surface quality) of the extruded semifinished goods. Purely empirical engineering methods for extrusion dies are becoming unacceptable at an increasing rate because of economical considerations.

The design of the flow channel takes a focal position in the engineering process of extruder dies. The book starts with identifying and explaining the necessary material data for designing the flow channel.

The derivation of basic equations permits to estimate pressure losses, forces acting on the channel walls, velocity profiles, average velocities e.t.c. in the flow channel. The simple equations which are useful for practical applications are summarized in tables. For the majority of extrusion dies they are sufficient to arrive at a realistic layout based upon rheological considerations.

Approaches to calculate the velocity and temperature fields using finite difference and finite element methods (FEM) are also discussed because of their increasing importance in connection with the layout of dies.

The various types of single and multiple layer extrusion dies and their specific feature are highlighted in detail in Chapter 5 and 6. Next follows a review of the thermal and mechanical design considerations, comments pertinent to the selection of material for extrusion dies and to their manufacture. A discussion of handling, cleaning and maintenance of extrusion dies as well as of devices for seizing of pipes and profiles concludes the book. At the end is a comprehensive list of references.

The book was written during my activity as head of the Section Extrusion and Injection Molding at the Institut für Kunststoffverarbeitung (IKV) at the Rheinisch-Westfälische Technische Hochschule Aachen (Institute for Plastics Processing at the Aachen Technical University, Aachen, West-Germany) (Director: Prof. Dr.-Ing. G. Menges). I had access to all important results of the research at the IKV in the field of engineering of extrusion dies. I like to extend my thanks to my former and present colleagues at the IKV in particular Messrs. I. Wortberg, A. Dierkes, M. Masberg, B. Franzkoch, H. Bangert, L. Schmidt, W. Predöhl, P.B. Junk, H. Cordes, R. Schulze-Kadelbach, P. Geisbüsch, P. Thienel, E. Haberstroh, G. Wübken, U. Thebing, K. Beiss, U. Vogt whose research work was essential in the preparation of the text and also to all other colleagues who contributed and to the students and graduate students of the Institute. But foremost I like to thank Prof. Dr.-Ing. G. Menges for encouraging me to prepare that book and for his ceaseless help, promotion and support which made it possible for me to complete it.

Further thanks are extended to a number of representatives of the plastics industry in particular to the members of the Section "Extrusion" and "Extrusion Blow Molding" of the Advisory Board of the Fördervereinigung (Sponsors Society) of the IKV.

Many of the research and development projects of the IKV which were referred to in this book and which became the basis for some of the facts presented in it, were only made possible financially due to the joint research between industry and the IKV, the support by the Arbeitsgemeinschaft Industrieller Forschungsvereinigungen (AIF), Cologne, the Deutsche Forschungsgemeinschaft (DFG), Bonn-Bad Godesberg and the Ministry for Research and Technology (BMFT), Bonn.

This book was first published in German language in 1979. The book in your hand is the first English translation based on this slightly revised 1979 edition.

We have added an alphabetic index and checked the list of reference to make sure that the most important references in English are easily identified.

Since 'life goes on' - also in extrusion tooling - the list of references is completed by publications since 1979.

I like to thank all who made this English version possible. The Society of Plastics Engineers (SPE) for sponsoring this book, Dr. Herzberg for translating, Dr. Immergut and Dr. Glenz of Hanser for coordinating, Dr. Hold of Polymer Processing Institute - Stevens Institute of Technology, Hoboken, New Jersey for being the technical editor and Hanser for publishing.

Heppenheim, W.-Germany
August 1983

Walter Michaeli

Contents

1. Introduction

The extrusion tool, which shapes the melt and which is also referred to as extrusion die or extruder head, as well as the generally adjacent former for guiding the semi-finished product in the molten state while maintaining the desired dimensions and at the same time achieving a specified degree of cooling, occupy a central position in the extrusion of thermoplastic materials to semi-finished products (Figs. 1.1 and 1.2).

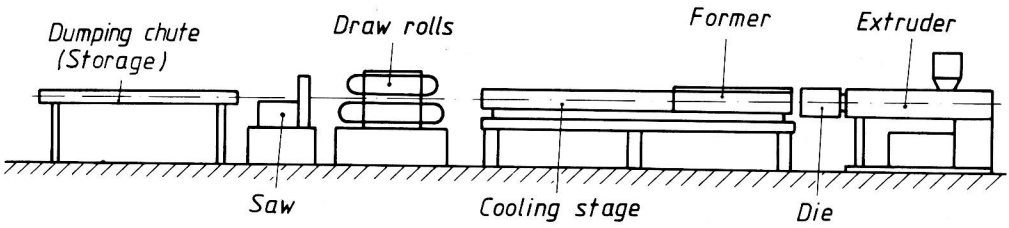

Figure 1.1: Principle of an extrusion plant for profiles

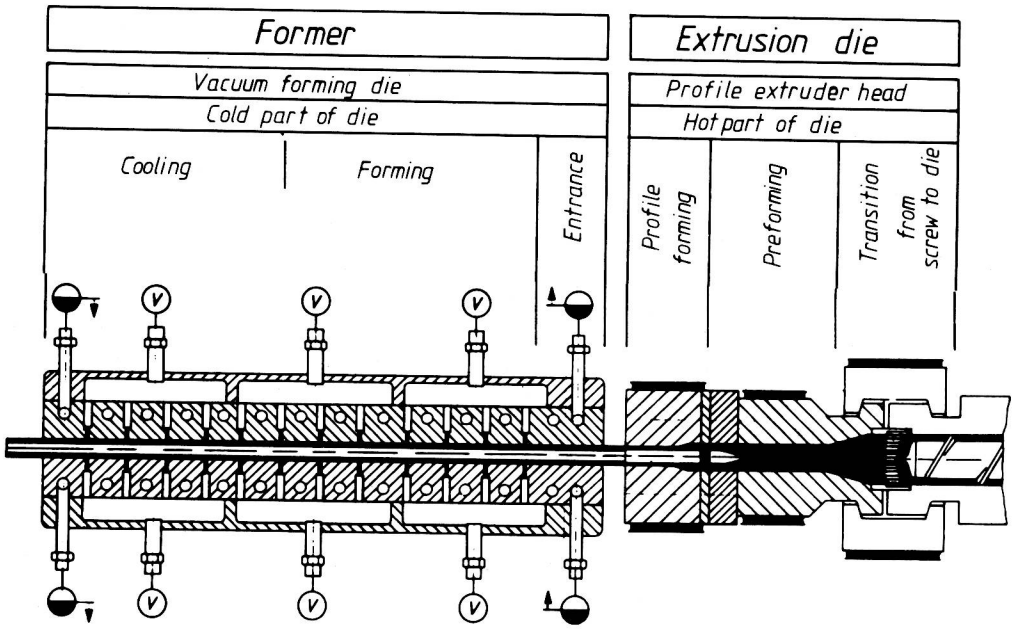

Figure 1.2: Tool sections (according to Reifenhäuser KG, Troisdorf)

A sufficiently large, pulsation-free, reproducible and thermally and mechanically homogeneous melt stream is expected from the extruder /1/. On the other hand, the extrusion die and the forming jig determine the dimensions of the semi-finished products. In this connection, it must be taken into consideration that the rheological and thermodynamic processes in the die and in the forming, as well as any stretching processes, which may be present between die and forming or in the connection to both, have a decisive effect on the quality of the extruded semi-finished products (e.g. surface, characteristic mechanical values). In order to design the extrusion die and the forming jig in a manner, which is appropriate from a process engineering point of view, it is therefore necessary to take into consideration the flow, deformation, and temperature relationships in both parts of the production line. If an analytical description of the physical processes is selected, the empirical portion in the design of the die and of the forming stage can be reduced, because changes, e.g. in the geometry of the channels of the die,in the operating conditions or in the rheological and thermodynamic material values of the plastic processed can be evaluated directly in regard to shaping and cooling of the extruded semi-finished products. This leads to a more reliable design of the extrusion die and of the forming.

It is therefore an objective of this book to provide a comprehensive representation of process engineering processes in extrusion dies and forming stages, attention being focused on a description of the extrusion die. Rules are derived from this for their design and simple mathematical aids are given, which conform to practical requirements. Moreover, reference is made to the special features of different designs for the die and forming jig.

In the construction and design of extrusion dies and forming jigs, rheological, thermodynamic, manufacturing as well as operational points of view arise /2/.

The o p e r a t i o n a l a s p e c t s include, for example, an adequate mechanical stiffness of the extrusion die, in order to keep changes in the cross section of the outlet, due to the action of melt pressure, to a minimum, the possibility of easily installing and dismantling the die and forming jig, and of readily cleaning the die, as well as as few as possible, well-sealed surfaces in the die, and a readily detachable and tight connection between extruder and die /2/.

Manufacturing points of view must be given consideration in the design of the individual die and forming jig components from the point of view of the lowest manufacturing costs - e.g. using die materials which lend themselves to machining, polishing and, if necessary, tempering (see Section 8.4), and employing established manufacturing methods.

In the rheological consideration, the question must be asked /2/: How should the dimension of the flow channel in the die be selected, so that:

- a specified volume throughput is achieved for a given extrusion pressure? (This question may also be reversed).

- the melt emerges at the same average rate from the whole of the outlet cross section?

- the desired extrudate geometry is achieved for semi-finished products without rotational symmetry? (This, inter alia, on the basis of viscoelastic effects (see Section 2.12 and 4.8).)

- the surface of the extrudate remains smooth even at high volume outputs? (At high shear rates, melt fracture may arise).

- stagnations and decompositions of the extruded material, which are partly associated with stagnations, are avoided? (This is a question of residence times of the material in the die as well as of the temperatures existing there.)

In the thermodynamic consideration of the problem, which is closely associated with the rheological consideration, information must be obtained concerning the maximum temperatures occurring in the melt stream in the die on the basis of existing heat transmission and dissipation relationships, especially in view of the heat-sensitive molding materials. This topic also includes the realization of a uniform and controllable temperature in the die and forming.

As a rule, not all of the subjects addressed here can be realized simultaneously with the same success when designing an extrusion die as well as