The Moldflow Design Guide is intended to help practicing engineers solve problems they encounter frequently in the design of parts and molds and during production. Today, the global imperative to drive down the cost of manufacturing has led to the use of molding simulation as a cost-optimization tool rather than just as a design and problem avoidance tool. It is critical for engineers in the plastics field to have access to flow analyses and their interpretations, including the simulation of cooling and warp effects, to aid in the successful design and manufacture of parts and molds.

The book provides an overview of the polymer flow behavior and the injection molding process, design principles to facilitate integrated part and mold design, and examples of how Moldflow design analysis technology can be used both to solve problems and to optimize the design of part, mold, and the molding process itself.

Contents:
- Polymer Flow Behavior in Injection Molds
- Molding Conditions and Injection Pressure
- Filling Pattern
- Moldflow Design Principles
- Meshes Used in Moldflow Analyses
- Product Design
- Gate Design
- Runner System Design
- Cooling System Design
- Shrinkage and Warpage
- Moldflow Design Procedure
- Part Defects
Jay Shoemaker (Editor)

Moldflow Design Guide
Moldflow Design Guide
A Resource for Plastics Engineers
The drive toward fast, cost-effective, and reliable plastics manufacturing has been Moldflow’s sole guiding goal since the company was founded over 25 years ago. This focused determination led us to introduce many new and exciting tools into the market, each contributing to achieving our goal in some way, whether by driving cost out of production with reduced material usage or shortened cycle times, reducing mold delivery time by minimizing re-work, or increasing the reliability of supply by enabling higher quality products to be manufactured with greater surety in scheduling.

The artificially balanced, multi-cavity and family molds that are now commonplace were made practical through the advent of our early simulation and runner balancing capabilities, which were introduced in the late 1970s and early 1980s. As these tools evolved, we were able to visualize, and therefore control, flow patterns and weld lines. This evolution continued until we arrived in the 2000s with an array of sophisticated technology to control warpage, account for heat transfer, predict core shift, adapt to new molding processes, and much more. From traditional midplane technology to fully three-dimensional simulations, all our solutions are well integrated into a solid-modeling design environment.

As the technology has evolved, so has its usage. When Moldflow simulation technology was introduced, its primary purpose was to search for remedies to pre-existing molding problems. It soon became evident that the insight the software provided to solve molding problems would be better applied ahead of actual molding, during the design process. This methodology, which we call “problem avoidance,” was the primary use for Moldflow technology for the first 20 years of its existence.

For Moldflow, this created a unique challenge: to open the world of manufacturing to the designers of parts and molds. What constitutes an ineffective design for molding may be apparent to a seasoned processing engineer looking retrospectively at a poorly performing tool, but how can design engineers use the CAE tools to visualize, diagnose and solve these same issues ahead of time—without 20 years of molding experience? How can manufacturers go further and use information that cannot be seen in the real molding process but is revealed via simulation?

The key that unlocked this puzzle began its life as the Moldflow Design Philosophy. This is widely viewed as the most important publication Moldflow has ever produced and has spawned follow-on works on related subjects. Rather than provide insight into the operation of the simulation tools, Moldflow Design Philosophy set forth simple principles that transcend any specific software application and, as a result, are as valid with today’s advanced simulation products as they were over two decades ago.

In more recent years, another transition has occurred. The global imperative to drive down the cost of manufacturing has led to the use of molding simulation as a cost optimization tool rather than for problem avoidance. This change has increased the number of Moldflow users by an order of magnitude across a far broader cross-section of the plastics industry. Greater design-centricity leads to even more dependence on the plastics design principles, which can be used to drive optimization.
Despite a quarter of a century of technological advances, the golden years of CAE are ahead of us as our industry takes a broader and more integrated view of what it takes to manage a product’s life cycle. Moldflow is proud of its contributions to date and will continue to focus on developing innovative technology coupled with practical design principles to deliver more profitable manufacturing.

Roland Thomas
President & CEO, Moldflow Corporation
Preface

About this Book

The origins of this book include not only Moldflow Design Principles, but also Warpage Design Principles published by Moldflow, and the C-MOLD Design Guide. Collectively, these documents are based on years of experience in the research, theory, and practice of injection molding. These documents are now combined into this book: the Moldflow Design Guide. The Moldflow Design Guide is intended to help practicing engineers solve problems they frequently encounter in the design of parts and molds, as well as during production. This book can also be used as a reference for training purposes at industrial and educational institutions.

How to Use this Book

This book has several chapters and appendices that deal with different stages of the design process and provides background on the injection-molding process and plastic materials.

• The first three chapters introduce injection molding how polymers flow inside injection molds and how molding conditions and injection pressure influence the process.
• Chapter 4 discusses Moldflow design principles and how they relate to making quality parts.
• Chapter 5 introduces the finite element mesh technology used by Moldflow and how these meshes influence the quality of the analysis.
• Chapters 6 to 9 introduce design concepts for the product, gates, runners, and cooling systems.
• Chapter 10 introduces concepts relating to shrinkage and warpage and how Moldflow is used to determine the amount of shrinkage and warpage a molded part will have and what causes the warpage.
• Chapter 11 discusses the design procedure for analyzing injection-molded parts.
• Chapter 12 discusses major part defects found on injection-molded parts.
• Finally, the four appendices discuss basic injection-molding machine operation, process control, variants of the standard injection-molding process, and plastic materials.

Benefits of Using CAE

The injection-molding industry has recognized that computer-aided engineering (CAE) enhances an engineer's ability to handle all aspects of the polymer injection-molding process, benefiting productivity, product quality, timeliness, and cost. This is illustrated by a wealth of
literature and the ever-growing number of CAE software users in the injection-molding industry.

**CAE Predicts Process Behavior**

Ideally, CAE analysis provides insight that is useful in designing parts, molds, and molding processes. Without it, we rely on previous experience, intuition, prototyping, or molding trials to obtain information such as polymer melt filling patterns, weld-line and air-trap locations, required injection pressure and clamp tonnage, fiber orientation, cycle time, final part shape and deformation, and mechanical properties of molded parts, just to name a few. Without CAE analysis, other equally important design data, such as spatial distributions of pressure, temperature, shear rate, shear stress, and velocity, are more difficult to obtain, even with a well-instrumented mold. The process behavior predicted by CAE can help novice engineers overcome the lack of previous experience and assist experienced engineers in pinpointing factors that may otherwise be overlooked. By using CAE analysis to iterate and evaluate alternative designs and competing materials, engineering know-how in the form of design guidelines can be established relatively faster and more cost-effectively.

**User Proficiency Determines the Benefits of CAE**

While CAE technology helps save time, money, and raw material, as well as cuts scrap, reduces the rejection rate, improves product quality, and gets new products to market faster, it is by no means a panacea for solving all molding problems. Rather, it should be recognized that CAE analysis is essentially a tool, designed to assist engineers instead of taking over their responsibilities or replacing them. Like many other tools, the usefulness of CAE technology depends on the proficiency of the user. The benefits mentioned above will not be realized unless the CAE tool is used properly. To be more specific, the accuracy of CAE analysis depends greatly on the input data provided by the user. In addition, the results generated by CAE analysis need to be correctly and intelligently interpreted by the user before sound judgments and rational decisions are made. Otherwise, users will simply be swamped by the vast amount of data without getting any useful information.
Acknowledgements

The Moldflow Design Guide would not have been accomplished were it not for the vision of Ken Welch. Ken and I have discussed the value of assembling the best of the Moldflow Design Principles, Warpage Design Principles, and the CA-MOLD Design Guide into a single book for several years. With Ken's leadership, he gave the project to Steve Thompson's training group, of which I am a part. Steve helped me coordinate the resources necessary to get this project done. I could not have done this project without Steve's help and guidance.

A review of the content was part of the development of the Moldflow Design Guide. Moldflow developers including Peter Kennedy, Rong Zheng, Zhongshuang Yuan, and Xiaoshi Jin have reviewed sections of the book. Moldflow's application engineers and other technical staff with Moldflow have also reviewed sections. These reviewers include Chad Fuhrman, Matt Jaworski, Christine Roedlich, Eric Henry, Olivier Anninos, Paul Larter, and Ana Maria Marin. A special thanks goes to Mike Rogers, who reviewed the entire book for me and provided critical feedback on the content and organization of the book. I would also like to thank Kurt Hayden of Western Michigan University for reviewing the appendix on process control. His many years of experience of process setup and optimization was invaluable.

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On a personal note, I would like to acknowledge and thank Paul Engelmann, Professor and Department Chair, Western Michigan University, Department of Industrial and Manufacturing Engineering, for being my friend and mentor during my career. With Paul, I have been able to teach and participate in research he has done on injection molding tooling and processing at Western Michigan University. I have found working with Paul has made me a better Moldflow user and engineer by providing another perspective on how Moldflow can be used to solve injection molding problems.

Jay Shoemaker, Editor
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