

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**PREDICTION OF PROBLEMS IN INJECTION
MOULDED PLASTIC PRODUCTS WITH COMPUTER
AIDED MOULD DESIGN SOFTWARE**

A thesis presented in partial fulfilment of the requirements

for the degree of

Masters In Technology in

Manufacturing and Industrial Technology

at

Massey University, New Zealand

Peter Ian Cayzer

1996

ABSTRACT

Several new technologies to assist plastic injection moulding companies have been developed in the last twenty years. A number of computer software programs are now available which could revolutionise mould design. The most exciting aspect of the Computer Aided Mould Design (CAMD) software is the effect it has on reducing the lead time required to produce a working mould from a product concept.

The application of the new technology for designing moulds, however, has been slow in New Zealand. One of the main reasons for the slow progress is the perceived value of the software or consulting services. Many injection moulding companies who design and manufacture moulds do not realise the great potential of CAMD software to save many hours of mould changes and volume of polymer material, even when the program is used after the mould has been made. However, the true benefits are only seen when the mould is designed using CAMD before the mould has been manufactured. Moulds manufactured correctly the first time save a great deal of time, energy and money. The value of the software is not completely understood by injection moulding manufacturers. They perceive the immediate benefits, however, the ongoing benefits are not recognised.

A project was carried out to demonstrate the potential of CAMD software in determining moulding problems in existing injection moulded products. Four products, two of which were supplied by an injection moulding company, that had moulding problems, were simulated using Moldflow, a CAMD software package. The results of the simulation were compared with the actual moulding problems.

It was found that the Moldflow simulation results described the problems occurring in the moulds accurately. Moulding problems included warpage, air traps and weld lines in poor positions and flow marks. Warpage is a major problem in injection moulded products. Even simple products can warp if not designed correctly.

The only problems Moldflow did not identify, and does not claim to, were the flow marks caused by jetting and splashing of plastic as it entered the cavity. The designer must be aware of the problems caused by jetting and design gates to avoid it.

Moldflow, and other CAMD software, are beneficial tools for the mould designer. The advantages of CAMD include short mould development time, shorter lead times from concept to production, reduction in the amount of material used, fewer changes to machine settings and predictable, repeatable quality. These benefits are not only savings in the mould design and manufacture, they also continue on into the processing of the product since less material is used in the product and machine down time caused by moulding problems is greatly reduced.

ACKNOWLEDGMENTS

To my supervisors, Ralph Ball, Alan Wright and David Morgan for their advice and assistance in developing the study this thesis addresses. Your guidance was invaluable at times when I needed to be reminded of the purpose of the project.

To Moldflow Australia Pty. Ltd. for their help and training during the past one and a half years. Their aid in the provision of training has made this study possible. I particularly wish to thank Derek Hain and Kate Hillman for their friendliness and assistance during the three week training course.

To Dr. Simon Hurley, whose numerous words of encouragement and advice guided me to the completion of this work. I am sincerely grateful for your support.

To Sunbeam Corporation Ltd. and Napier Tool and Die Ltd., for providing projects for the study. I particularly wish to thank Craig Dais and Peter Whitburn of Sunbeam whose cooperation has been greatly appreciated. Thank you for your support.

To my family and friends, too many to name, I appreciate your love and support over the past two years which has kept me going during the struggles.

To my wife, Fiona, whom I love dearly and thank for being patient and understanding of my needs during this extended life episode.

This thesis is dedicated to my parents whose persistent encouragement and vision has led me on an exciting and educational journey. Thank you both.

My life journey has given me eternal hope in Jesus Christ and I must finish by giving Him thanks for the endless grace, peace and love He gives.

TABLE OF CONTENTS

ABSTRACT	ii
ACKNOWLEDGMENTS.....	iv
TABLE OF CONTENTS.....	v
LIST OF FIGURES	viii
LIST OF TABLES	ix
CHAPTER ONE : INTRODUCTION TO MOULD DESIGN	1
1.1 SUMMARY.....	2
1.2 PROJECT OBJECTIVES	3
1.3 OUTLINE OF THE REPORT	4
CHAPTER TWO : MOULD DESIGN TOOLS.....	5
2.1 INTRODUCTION	6
2.2 BASIC DESIGN PRINCIPLES	7
2.2.1 Gates.....	8
2.2.1.1 Uniform Filling.....	9
2.2.1.2 Jetting.....	9
2.2.1.3 Gate Position	9
2.2.2 Runners.....	12
2.2.3 Product Wall Thickness	12
2.2.4 Filling Analysis	13
2.3 CONVENTIONAL MOULD DESIGN	14
2.3.1 Conventional Runner Design.....	15
2.3.2 Filling Image.....	16
2.4 COMPUTER AIDED MOULD DESIGN	17
2.4.1 Computer Aided Mould Design Concepts	19
2.4.2 2D Modeling	20
2.4.2.1 Flow Path	22
2.4.2.2 Flow Balance	22
2.4.2.3 Gate and Runner Sizing	23
2.4.3 3D Modeling	24
2.4.3.1 Gate Positioning	25
2.4.3.2 Flow Analysis	25
2.4.3.3 Warpage Control.....	26
2.4.3.4 Cooling System Design	29
2.4.4 Capabilities.....	30
2.4.5 Limitations	31
2.5 CONCLUSION	31
CHAPTER THREE : MOULD DESIGN - THE PROBLEM.....	32
3.1 INTRODUCTION	33
3.2 MOULDING DIFFICULTIES	34
3.2.1 Polymer Rheology.....	35
3.2.2 Long, usually unknown, development time.....	36
3.2.3 Small Moulding Window.....	36
3.2.4 Tooling Cost.....	36
3.2.5 Excessive Material in the Runner System	37
3.2.6 Low Product Quality	38
3.2.7 Low Creativity.....	39
3.3 RESOLVING MOULDING PROBLEMS	40
3.4 BENEFITS OF CAMD.....	41

CHAPTER FOUR : RESEARCH METHODOLOGY.....	43
4.1 INTRODUCTION	44
4.2 PROJECT SELECTION.....	45
4.3 DATA COLLECTION	45
4.4 DESIGN ANALYSIS.....	48
4.5 COMPARISON OF MOLDFLOW RESULTS AND OBSERVED PROBLEMS.....	51
CHAPTER FIVE : PROJECT DESCRIPTIONS AND RESULTS.....	53
5.1 STORAGE BOX - MASSEY UNIVERSITY, PRODUCTION TECHNOLOGY	54
5.1.1 Summary	54
5.1.2 Moldflow Simulation of the Box Model.....	55
5.1.3 Storage Box Moulding Problems	57
5.1.4 Comparison of Results.....	58
5.1.5 Design Changes and Results.....	59
5.2 PLANTER POTS - MASSEY UNIVERSITY, PRODUCTION TECHNOLOGY	61
5.2.1 Summary	61
5.2.2 Moldflow Simulation Results for the Planter Pot Model.....	63
5.2.3 Planter Pot Moulding Problems	64
5.2.4 Comparison of Results.....	65
5.3 CROCKPOT LID KNOB - SUNBEAM.....	66
5.3.1 Summary	66
5.3.2 Moldflow Simulation of the Knob Model.....	67
5.3.3 Knob Moulding Problems.....	69
5.3.4 Comparison of Results.....	69
5.4 STRIPS FOR BENCH TOP OVEN - SUNBEAM.....	71
5.4.1 Summary	71
5.4.2 Moldflow Simulation of the Strips.....	72
5.4.3 Strip Moulding Problems.....	73
5.4.4 Comparison of Results.....	74
5.5 SUMMARY.....	75
5.6 CONCLUSIONS.....	78
CHAPTER SIX : CONCLUSIONS	80
6.1 SUMMARY.....	81
6.2 FURTHER WORK.....	83
APPENDIX A1 : MOULD DESIGN PROCEDURE.....	85
A1.1 PROJECT PLAN	86
A1.2 DEFINE END USE REQUIREMENTS.....	87
A1.3 PRELIMINARY CONCEPT SKETCH.....	88
A1.4 MATERIAL SELECTION	88
A1.5 PART DESIGN	89
A1.6 MODIFY PART FOR MANUFACTURING	89
A1.7 PROTOTYPING	89
A1.8 PRODUCTION TOOLING	90
A1.9 MANUFACTURING.....	90
APPENDIX A2 : COMPUTER AIDED MOULD DESIGN SOFTWARE	91
A2.1 MOLDFLOW PTY. LTD. - MOLDFLOW	92
A2.2 PLASTICS & COMPUTER - TMCONCEPT	94
A2.3 SDRC - I-DEAS MASTER SERIES	95
A2.4 AC TECHNOLOGY - C-MOLD.....	96
A2.5 IKV - CADMOULD.....	98
A2.6 SUMMARY OF SOFTWARE	99
APPENDIX A3 : GATE DESIGNS	100
A3.1 INTRODUCTION	101

A3.2 LARGE	101
A3.3 RESTRICTED	101
A3.4 SPRUE	102
A3.5 FAN	103
A3.6 DIAPHRAGM AND RING	103
A3.7 SUBMARINE.....	104
APPENDIX A4 : PROJECT SIMULATIONS AND ANALYSIS.....	105
A4.1 STORAGE BOX - MASSEY UNIVERSITY, PRODUCTION TECHNOLOGY	106
A4.1.1 Product Description.....	106
A4.1.2 Material Specifications	107
A4.1.3 Flow Paths.....	107
A4.1.4 Results of a 2D Path Analysis	108
A4.1.5 3D Model Simulation Analysis.....	108
A4.1.6 Comparison	109
A4.1.7 Design Changes and Results	109
A4.2 PLANTER POTS - MASSEY UNIVERSITY, PRODUCTION TECHNOLOGY.....	117
A4.2.1 Product Description.....	117
A4.2.2 Material Specifications	117
A4.2.3 Flow Paths for Planter Pots	118
A4.2.4 Results of a 2D Path Analysis	118
A4.2.5 3D Model Simulation Analysis	119
A4.2.6 Comparison	119
A4.3 CROCKPOT LID KNOB - SUNBEAM	123
A4.3.1 Product Description.....	123
A4.3.2 Material Specifications	123
A4.3.3 Flow Path	124
A4.3.4 Results of a 2D Path Analysis	124
A4.3.5 Model Simulation Analysis.....	125
A4.3.6 Comparison	125
A4.4 BENCH TOP OVEN STRIP	127
A4.4.1 Product Description.....	127
A4.4.2 Material Specifications	127
A4.4.3 Flow Paths.....	128
A4.4.4 Results of a 2D Path Analysis	128
A4.4.5 Model Simulation Analysis.....	128
A4.4.6 Comparison	128
BIBLIOGRAPHY	131

LIST OF FIGURES

FIGURE 2.1 GATE DESIGN TO AVOID JETTING	11
FIGURE 2.2 POOR BOSS DESIGN VERSUS GOOD BOSS DESIGN	13
FIGURE 2.3 DIMENSIONING RUNNERS APPLICABLE FOR PS, ABS, SAN, CAB PLASTICS.	16
FIGURE 2.4 CORRECTION TERM DETERMINATION.....	16
FIGURE 2.5 FILLING IMAGE.....	17
FIGURE 2.6 AN EXAMPLE OF A MOULDING WINDOW.	21
FIGURE 2.7 FLOW PATHS OF A SIMPLE PRODUCT	22
FIGURE 2.8 DIFFERENTIAL ORIENTATION	27
FIGURE 2.9 DIFFERENTIAL CRYSTALLINITY.....	28
FIGURE 2.10 DIFFERENTIAL COOLING	28
FIGURE 2.11 TYPICAL COOLING CIRCUITS.....	30
FIGURE 4.1 MOULDING WINDOW QUADRANTS	48
FIGURE 5.1 STORAGE BOX.....	54
FIGURE 5.2 MOULDING WINDOW.....	56
FIGURE 5.3 PLANTER POTS.....	62
FIGURE 5.4 MOULDING WINDOW.....	63
FIGURE 5.5 CROCKPOT LID KNOB.....	66
FIGURE 5.6 MOULDING WINDOW FOR THE KNOB.....	68
FIGURE 5.7 STRIPS FOR THE BENCH TOP OVEN	71
FIGURE 5.8 MOULDING WINDOW FOR THE STRIPS.....	73
FIGURE A2.1 TMCONCEPT SOFTWARE REQUIREMENTS	95
FIGURE A3.1 DIAPHRAGM AND RING GATES	104
FIGURE A3.2 SUBMARINE GATE	104
FIGURE A4.1 STORAGE BOX.....	106
FIGURE A4.2 FLOW PATHS	107
FIGURE A4.3 MOULDING WINDOW	109
FIGURE A4.4 THICKNESSES PLOT (DIMENSIONS : MILLIMETRES).....	110
FIGURE A4.5 FILLING AND AIR TRAPS PLOT (SCALE : SECONDS).....	110
FIGURE A4.6 END OF FILL PRESSURE PLOT (SCALE : MPA)	111
FIGURE A4.7 END OF FILL TEMPERATURE PLOT (SCALE : °C).....	111
FIGURE A4.8 WARPAGE IN THE REAR WALL OF THE PRODUCT	112
FIGURE A4.9 WARPAGE IN THE BASE OF THE PRODUCT.....	112
FIGURE A4.10 SHORT SHOT AT 70% FILLED	113
FIGURE A4.11 FILL TIME CONTOUR PLOT AT 70% FILLED (SCALE : SECONDS).....	113
FIGURE A4.12 VISIBLE FLOW MARKS AND AIR TRAP.....	114
FIGURE A4.13 FILL TIME CONTOUR PLOT AT 100% FILLED (SCALE : SECONDS).....	114
FIGURE A4.14 SHORT SHOT AT 70% FILLED, AFTER CHANGES.....	115
FIGURE A4.15 FILL TIME PLOT AT 70% FILLED, AFTER CHANGES (SCALE : SECONDS).....	115
FIGURE A4.16 COMPLETE STORAGE BOX AFTER CHANGES.....	116
FIGURE A4.17 FILL TIME CONTOUR PLOT, AFTER CHANGES (SCALE : SECONDS)	116
FIGURE A4.18 PLANTER POTS	117
FIGURE A4.19 FLOW PATHS	118
FIGURE A4.20 MOULDING WINDOW FOR PLANTER POTS	119
FIGURE A4.21 WELD LINE PLOT.....	120
FIGURE A4.22 FLOW FRONT TEMPERATURE PLOT. (SCALE : °C).....	120
FIGURE A4.23 FILL TIME PLOT, SHORT SHOT (SCALE : SECONDS)	121
FIGURE A4.24 PRESSURE PLOT, SHORT SHOT (SCALE : MPA)	121
FIGURE A4.25 WARPAGE IN THE TOP OF THE PLANTER POT	122
FIGURE A4.26 LAST POINT TO FILL	122
FIGURE A4.27 CROCKPOT LID KNOB	123
FIGURE A4.28 FLOW PATHS FOR THE CROCKPOT LID KNOB.....	124
FIGURE A4.29 MOULDING WINDOW FOR THE KNOB	124
FIGURE A4.30 FLOW FRONT TEMPERATURE FOR THE KNOB (SCALE : °C)	126
FIGURE A4.31 RIPPLES IN THE KNOB, THROUGH POLARISED FILTERS.....	126
FIGURE A4.32 STRIP	127
FIGURE A 5.33 MOULDING WINDOW FOR THE STRIPS	129

FIGURE A4.34 FILL TIME PLOT FOR THE STRIP (SCALE : SECONDS)	129
FIGURE A5.35 FLOW FRONT PRESSURE FOR THE STRIP	130
FIGURE A4.36 WARPAGE IN THE STRIPS	130

LIST OF TABLES

TABLE 2.1 FACTORS DETERMINING THE LOCATION, SIZE AND TYPE OF GATE.....	5
TABLE 4.1 2D ANALYSIS PROBLEMS.....	50
TABLE 4.2 3D MODEL SIMULATION RESULTS.....	52
TABLE 5.1 MOLDFLOW RESULTS AND USER-DEFINED PROBLEMS FOR THE STORAGE BOX	39
TABLE 5.2 MOLDFLOW RESULTS AND USER-DEFINED PROBLEMS FOR THE PLANTER POTS	42
TABLE 5.3 MOLDFLOW RESULTS AND USER-DEFINED PROBLEMS FOR THE PLANTER POTS	45
TABLE 5.4 MOLDFLOW RESULTS AND USER-DEFINED PROBLEMS FOR THE STRIPS.....	47
TABLE 5.5 TYPES OF PROBLEMS SOLVED BY MOLDFLOW, CONFIRMED IN RESULTS.....	48
TABLE A1.1 MATERIAL SELECTION RATING.....	56
TABLE A2.1 SUMMARY OF CAMD SOFTWARE.....	63

CHAPTER ONE

INTRODUCTION TO MOULD DESIGN

1.1 SUMMARY.....	2
1.2 PROJECT OBJECTIVES	3
1.3 OUTLINE OF THE REPORT	4

Mould design for the injection moulding process has changed from a technique requiring years of experience to one that incorporates experience and design simulation. This chapter gives a brief overview of the evolution of Computer Aided Mould Design software, presents a summary of the body of this thesis and introduces the hypothesis this thesis addresses.

1.1 Summary

Injection moulding is the most widely used process in the plastics industry for manufacturing plastic products. The injection moulding process requires three main components; an injection unit, a clamping device and a mould. The mould is the subject of this thesis, in particular, the design of the mould, how well Computer Aided Mould Design (CAMD) software can predict moulding problems and how useful the software is as a cost effective adjunct to the mould designer's judgment.

In the past, mould design has been an art, rather than a science. This is mainly due to the difficulties in moulding polymers into the required shapes using a high pressure process like injection moulding. The characteristics of polymer flow under high pressures and the intricacies of the injection moulding process were understood by very few designers, hence many designs required a great deal of rework before reaching production status. This continues to be a problem with mould design since the rheology of polymers under high stresses and changing temperatures is complex and difficult to solve.

The problem could not really be overcome until computers with the power to solve the complex simultaneous flow and heat equations were available. Now that these computers are available, it is possible to not only solve the equations, but also provide graphical results that give a clear picture of what occurs in the mould as the polymer flows through it, cools and freezes. These displays are available in software packages specially designed for assisting in the design of injection moulding moulds.

The software packages are aids to the designer. A good mould designer is required to analyse the output from the mould model simulation and make the necessary changes to the model to improve the design. The designer requires not only training in using the software package, he/she also requires knowledge of the properties of polymers and mould design procedures and concepts. The latter requirements may take several years to build up to a point where the mould designer is proficient at what he/she does.

A survey carried out in 1994 by Xiaoping Pan discovered that 83% of the New Zealand plastics industry realised that "tool and die making had become an important

part of the New Zealand Plastics Industry.” Several of the comments from the industrial survey included: “In an effort to become cost competitive, die making and design is a key component.” “High quality tool and die making is a key to success.” “Sometimes it is the limitation of the die or tool that prevents the product being made.”

The Production Technology department is eager to develop expertise in injection moulding technology. This thesis is part of the development. Moldflow, the sophisticated mould design software has been made available to the department for teaching and research purposes by Moldflow of Australia.

The introduction to this thesis will describe the project objectives in section 1.2 and the outline of the thesis in section 1.3.

1.2 Project Objectives

There are three distinct objectives this thesis addresses:

1. To determine the benefits of computer software for the analysis of injection moulds through verification techniques. This will be carried out by studying several products, analysing them using Moldflow and drawing conclusions regarding the effectiveness of the software to predict moulding problems in the mould design.
2. To increase the Production Technology Department’s awareness of available technology for injection moulding.
3. To develop an understanding of the concepts behind Computer Aided Mould Design software.

Hypothesis : Computer Aided Mould Design software can accurately predict moulding problems, namely: quality, processability and in-service requirements in a product that are not met.

1.3 Outline of the report

Mould design is an important part of the moulding process. A well designed, manufactured mould will not only last, it will also be able to produce a consistent product. Mould design can be complicated, especially when small tolerances, thin sections and complex structures are required. A design that performs the task well may not necessarily mould well in the injection moulding machine. It is therefore important to use a procedure to design the best possible mould.

Computer Aided Mould Design is a major development in the mould design field. However, it has not, as yet, been widely adopted in New Zealand. More companies are beginning to see the rewards of such a product, but this has been slow. Gallagher Plastics and Fisher and Paykel are two New Zealand companies who have begun to use CAMD in the last five years. Other companies, such as Whitfield Design, Sunbeam and Coxen and Standish have utilised the services of one or more of the CAMD consulting agents in New Zealand or Australia. Mould designers may require further educating in the benefits of Computer Aided Mould Design so that they may understand and see the real benefits of such an aid. Most injection moulding companies who have used CAMD consulting in the past have considered the cost of the analysis too high and have discarded the need for it.

To gain an understanding of the great potential of Computer Aided Mould Design software, a familiarity with the injection moulding process and the rheology of polymers is required, as well as a solid grasp of mould design. This thesis includes a discussion of the mould design tools currently available. The background sections will be followed by the reasoning behind using CAMD. Chapter 4 develops the research methodology and chapter 5 presents the projects that have been carried out using one of the software packages. The aim of these projects was to determine the ability of Computer Aided Mould Design software to predict possible problems that occur in the mould. These problems may relate to warpage, poor material flow, poor design, air traps, etc which result in poor product quality, poor processability and in-service requirements that are not met.

A discussion of any further work that could be carried out in this area and an overview of the results of the projects concludes the thesis.