

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.

Electrical Discharge Machining and Rapid Manufacture of Injection Moulding Tools

A Thesis presented in partial fulfilment of the
requirements for the degree
of Master of Technology in
Manufacturing and Industrial Technology at
Massey University

W.W.F.Jayasuriya

1997

To
Percy Jayasuriya
with greatest gratitude

Abstract

This thesis presents how rapid manufacture of injection moulding tools could be adopted in the New Zealand manufacturing environment.

The approach is to study about the conventional methods, machinery and the materials of moulding tools and their limitations, application of modern machinery, NC programming, CNC programming using commercially available software to generate NC codes, use of high level programming language to generate NC codes. Further practical difficulties and limitations of modern methods of design and manufacture will be discussed. Finally, the application of electrical discharge machine in rapid manufacture of moulding tools will be studied as an alternative solution to overcome the difficulties in modern methods.

A study of an alternative moulding tool materials and EDM tool materials will be carried out.

Since there is no guidance in predicting the machining speed and the surface finish of the EDM process in most available manuals a special study has been carried out, to determine both machining speed and surface finish in terms of available EDM process variables.

Experimental design technique was used to collect data and graphical and statistical analysis has been used to identify significant factors. By collecting data after further experimentation and regression analysis using statistical software package called MINITAB release 10, relationships for machining speed, surface finish with available process variables have been established.

Finally some conclusions in rapid manufacture of injection moulding tools appropriate to New Zealand environment will be discussed in the last chapter of this thesis.

Acknowledgements

First and foremost the author would like to thank Professor Don Barnes for providing encouragement to study Masters of Technology degree in this university. Also his weekly meetings and discussions in design of experiment and multivariate analysis were very useful to the author during his study.

Author specially thanks to his supervisor Mr Harvey Barrcolough for valuable, sincere advises and guidance given to him in making this study. Author was able to finish this study so quickly mainly due to Mr Barrcolough's frequent encouragement and advises which he can not forget.

In addition to that, Author would like to express his thanks to Mr Lyndon Kapoor the director of Metrology Calibration Services Ltd, Hamilton for quick actions to measure and send surface roughness values.

Also Author expresses his special thanks to Mr Merv Foot and Mr. Leith Baker for providing him frequent assistance and advises in using machinery and equipment, computers and software in the departmental industrial engineering laboratory.

Author can not forget the help given by all other staff in the department of production technology and his colleagues which he can not mention separately.

Finally author thanks to his beloved wife and two children who very patiently extended their corporation and support.

CONTENTS

Title Page

Abstract

Acknowledgements

Contents

List of figures

List of Tables

Chapter 1

Introduction and Overview of Thesis 1

1.1 Foreword 2

1.2 Objectives of the Research Work 3

1.3 Summary of Contents 4

1.4 General References 4

Chapter 2

Injection Moulding process 5

2.1 Injection Moulding 6

2.2 Injection Moulding Machine 7

2.3 Types of Injection Moulding Machines 7

2.4 Important Parts of Conventional Injection Moulding Machine 10

2.5 Description of the Injection Moulding Machine at the
departmental Industrial Engineering Laboratory 12

Chapter 3

Description of Injection Moulding Tool	14
3.1 Difficulties in Injection Moulding	15
3.2 Overcoming Difficulties by Quality of Design and Manufacture	15
3.3 Various Moulding Tool Designs	21
3.4 Materials for Manufacture of Moulding Tools	27
3.5 Common Moulding problems and their causes	30

Chapter 4

Use and Effect of Conventional Machinery in Rapid Manufacture of Moulding Tools	33
4.1 Centre Lathe	34
4.2 Milling Machine	34
4.3 Shaping Machine	35
4.4 Drilling Machine	35
4.5 Surface Grinder	36
4.6 Concept of Rapid Manufacture of Moulds	36
4.7 Effect of Conventional machinery on rapid mould manufacture	40

Chapter 5

Modern Manufacture Of Injection Moulding Tools	45
5.1 Copy Milling Machine/ Pantograph	47
5.2 NC Milling Machines	51
5.3 CNC Milling Machine at the Departmental Industrial	

Engineering Laboratory	51
5.4 Effect of NC Machining for Rapid Manufacture of Moulds	53
5.5 CNC Programming In G Code and Heidenhein Code	53
5.6 Problems in NC Machining.	57
5.7 Computer Programming for Free Form Curves and Surfaces	57
5.8 Automatic CNC Program Generation using CAD/CAM	58
5.9 Problems in using Computer Programming and Software in Rapid Manufacture of Moulds	60
5.10 Introduction to the Electrical Discharge Machine	61
5.11 Important Parts of EDM System	61
5.12 Principle of Operation	64
5.13 Selection of Electrode Materials	67
5.14 Applications, Advantages and Health and safety	68
5.15 Process Parameters available in EDM	70
5.16 Description of EDM at the Departmental Industrial Engineering Laboratory	71
5.17 Problems in EDM during Rapid Manufacture of Moulds	73
5.18 Identification of Important Parameters affects the Cutting speed and the Surface Quality	74
5.19 The Necessity of Establishment of Relationships	74

Chapter 6

Design of Experiment And Analysis of Results	76
6.1 Introduction	78
6.2 Experimental Design	79
6.3 Further Experimental Design	85
6.4 Current Flow (I)	88
6.5 Rate of Penetration	96
6.6 Surface Roughness	105
6.7 Comparison between Copper and Aluminium electrode on surface quality	117

6.8 Discussion.	119
-----------------	-----

Chapter 7

Verification of Relationships	122
--------------------------------------	-----

7.1 Current Flow (I)	123
-----------------------------	-----

7.2 Rate of Penetration	124
-------------------------	-----

7.3 Surface Roughness	125
-----------------------	-----

7.4 Conclusions	126
-----------------	-----

Chapter 8

Conclusions For the Development of Rapid Tool Manufacture Appropriate to the New Zealand Manufacturing Environment	128
---	-----

8.1 Introduction	129
------------------	-----

8.2 Conclusions	129
-----------------	-----

References	134
-------------------	-----

Appendices	136
-------------------	-----

List of Figures

2.1	Principle of plunger type moulding machine	8
2.2	Parts of screw type moulding machine	9
2.3	Manual type moulding machine	10
2.4	Departmental Injection moulding machine	13
3.1	Parts of conventional moulding tool	16
3.2	Basic mould configuration	17
3.3	Inserts and bolsters	17
3.4	Sprue and sprue bush	18
3.5	Effect of misalignment between sprue bush and injection nozzle	19
3.6	Different runner systems	20
3.7	Sprue and sprue puller	21
3.8	Various designs of ejection pins	22
3.9	Typical ejection action	22
3.10	Standard mould	23
3.11	Moulds with stripper plates	24
3.12	Slide mould	25
3.13	Split cavity mould	26
3.14	Moulds with unscrewing device	27
4.1	Parts of split mould	35
4.2	Interdependence factors in mould design and manufacture	38
4.3	Conventional sequence in mould manufacture	39
4.4	Non symmetrical cavities	40
4.5	Non alignment of guiding holes	40
4.6	Non uniform thickness between cavity and core	41
4.7	Non identical cavities	42
4.8	Basic designs of runner and gate systems	42
4.9	An example of a shape of mould cavity	43

5.1	A typical NC machine	49
5.2a-5.2b	Punch tape and Standard EIA tape code	50
5.3a	Open and closed loop systems	51
5.4	Departmental CNC milling machine	52
5.5	Right hand Cartesian co-ordinate system	53
5.6	An example profile	54
5.7	Free form curve	58
5.8	Automatic CNC program generation	60
5.9	Schematic diagram of EDM	63
5.10	Various flushing systems	64
5.11	Principle of operation	65
5.12	Application examples of EDM	68
5.13	Typical pulse train in EDM operation	70
5.18	Departmental electrical discharge machine	75
6.1	Copper electrode 1cm^2	81
6.2	Copper electrode 2 cm^2	82
6.3	I vs T_{OFF}	89
6.4	I vs G_V	90
6.5	I vs T_{ON}	90
6.6	I vs I_P	91
6.7	Significant effect plot for I	93
6.8	Plot P_R vs T_{OFF}	97
6.9	Plot P_R vs G_V	97
6.10	Plot P_R vs T_{ON}	98
6.11	Plot P_R vs I_P	99
6.12	Significant effect plot for P_R	100
6.13	Plot for P_R vs (I/A)	103
6.14	Wave form of dc electrical pulse	103
6.15	Surface profilometer	106
6.16	Corresponding S_R values in table 6.12	106
6.17	Plot S_R vs T_{OFF}	108

6.18	Plot S_R vs G_V	108
6.19	Plot S_R vs T_{ON}	109
6.20	Plot S_R vs I_p	110
6.21	Significant effect plot for S_R	111
6.22	Different S_R values of side 2 of the work piece	112
6.23	S_R values of side 3 of the work piece	115
6.24	$\text{Log}_e(S_R)$ vs $\text{Log}_e(T_{ON})$	116
6.25	Tool electrode with 2 cm^2 cross sectional area	118
7.1	Current Flow- Actual vs Estimated	124
8.1	Rapid manufacture of injection moulding tool	133

List of Tables

6.1	Plackett Berman two level design matrix	79
6.2	Factors for Plackett-Berman experiment	80
6.3	Treatment table for Plackett-Berman experiment	80
6.4	Rate of penetration – Plackett-Berman design	81
6.5	Surface Roughness – Plackett-Berman design	82
6.6	Effect analysis for P_R	83
6.7	Effect analysis for S_R	83
6.8	Effect analysis for I	85
6.9	Two level full factorial design matrix	86
6.10	High and low values for factors	87
6.11	Treatment table for two level full factorial design	87
6.12	Observations for current flow	88
6.13	I vs T_{OFF}	89
6.14	I vs G_V	89
6.15	I vs T_{ON}	90
6.16	I vs I_P	91
6.17	Yates analysis for I	92
6.18	Significant effect for I	92
6.19	I vs I_P , T_{ON} and T_{OFF}	95
6.20	Observations for penetration	96
6.21	P_R vs T_{OFF}	96
6.22	P_R vs G_V	97
6.23	P_R vs T_{ON}	98
6.24	P_R vs I_P	98
6.25	Yates Analysis for P_R	99
6.26	Significant effects for P_R	100
6.27	P_R vs Current Density	102
6.28	Observations for surface roughness	107
6.29	S_R vs T_{OFF}	107
6.30	S_R vs G_V	108

6.31	S_R vs T_{ON}	109
6.32	S_R vs I_P	109
6.33	Yates analysis for surface roughness	110
6.34	Significant effects for S_R	111
6.35	S_R with changing T_{ON}	113
6.36	S_R values with changing T_{ON} and I_P	114
6.37	Effect of electrode material on surface quality	118
6.38	Wear rates of Cu and Al electrode tools	118
7.1	Experimental observations for P_R	123
7.2	Actual current flow vs Estimated current	123
7.3	Actual vs Estimated P_R	125
7.4	Experimental observations for S_R	126