



**MULTI-RESPONSE INJECTION MOULDING PROCESS  
PARAMETERS OPTIMIZATION USING TAGUCHI  
METHOD WITH GREY RELATIONAL ANALYSIS**

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OPTIMIZATION USING TAGUCHI METHOD WITH GREY RELATIONAL  
ANALYSIS**

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in fulfillment of the requirements for the degree of Master of Science  
in Manufacturing Engineering**

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**2018**

## DECLARATION

I declare that this thesis entitled “Multi-response Injection Moulding Process Parameters Optimization Using Taguchi Method with Grey Relational Analysis” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : .....

Date : .....

## APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Manufacturing Engineering.

Signature :.....

Supervisor Name :.....

Date :.....

## **DEDICATION**

To my beloved family members.

## ABSTRACT

Plastic injection moulding is one of the important processes to produce the plastic product with complex shape and high accuracy. The quality of the plastic product in plastic injection moulding process is affected by four factors, and that factors are plastic materials, mould design, machine parameters and production operator. It is well known that in industry practice, machine parameters are changed by the skill of experienced operator using trial and error method. Therefore, process parameters should be optimized using the proper method such as the design of experiment (DOE). The purpose of this study is to examine the process parameters for injection moulding on material characteristics such as part weight, warpage, geometrical shrinkage and mechanical properties. In mechanical properties, ultimate tensile strength, tensile modulus and percentage of elongation were studied. The parameters involved in this study were mould temperature, melt temperature, injection time and cooling time. Taguchi method was used where L9 with nine runs with three repetitions were conducted. The optimization is carried out in two ways by using single response and multi-response of Taguchi method based grey relational analysis (GRA) for all responses. Hence, the optimum result of the single response for part weight is the mould temperature which contributes 58.88%. Meanwhile, for warpage, melt temperature contributes 38.96%. For shrinkage, mould temperature contributes 67.76%. For mechanical properties such as ultimate tensile strength and tensile modulus, mould temperature contributes 93.33% and 40.37%, respectively. For the percentage of elongation, melt temperature contribution is 51.41%. Multi-response optimization shows that a set of input parameters for all responses are mould temperature at 56°C, melt temperature at 250°C, injection time at 0.7s and cooling time at 15.4s. ANOVA result shows that cooling time contributes 86.76% for all responses. Therefore, the multi-response optimization can predict the quality of plastic product produced in plastic injection moulding process.

## **ABSTRAK**

*Pengacuan suntikan plastik adalah salah satu proses penting untuk menghasilkan produk plastik dengan bentuk yang kompleks dan ketepatan yang tinggi. Kualiti produk plastik dalam proses pengacuan suntikan plastik terjejas oleh empat faktor, dan faktor tersebut adalah bahan plastik, reka bentuk acuan, parameter mesin dan pengendali pengeluaran. Adalah diketahui bahawa dalam amalan industri, parameter mesin diubah oleh kemahiran pengendali yang berpengalaman menggunakan kaedah percubaan dan kesalahan. Oleh itu, parameter proses perlu dioptimumkan menggunakan kaedah yang sesuai seperti reka bentuk eksperimen. Tujuan kajian ini adalah untuk mengkaji parameter proses untuk pengacuan suntikan pada ciri-ciri material seperti berat produk, keledingan, pengecutan geometri dan sifat mekanikal. Dalam sifat mekanikal, kekuatan tegangan muktamad, modulus tegangan dan peratusan pemanjangan telah dikaji. Parameter yang terlibat dalam kajian ini ialah suhu acuan, suhu leburan, masa suntikan dan masa penyejukan. Kaedah Taguchi digunakan di mana L9 dengan sembilan eksperimen dengan tiga kali pengulangan dilakukan. Pengoptimuman dilakukan dalam dua cara dengan menggunakan respon tunggal dan multi-respon analisis relasi kelabu (GRA) berasaskan kaedah Taguchi untuk semua tindak balas. Oleh itu, hasil optimum respon tunggal untuk bahagian berat adalah suhu acuan yang menyumbang 58.88%. Sementara itu, untuk keledingan, suhu leburan menyumbang 38.96%. Untuk pengecutan, suhu acuan menyumbang 67.76%. Untuk sifat mekanikal seperti kekuatan tegangan muktamad dan modulus tegangan, suhu acuan masing-masing menyumbang 93.33% dan 40.37%. Untuk peratusan pemanjangan, sumbangan suhu leburan ialah 51.41%. Pengoptimuman multi-respon menunjukkan bahawa satu set parameter input untuk semua tindak balas adalah suhu acuan pada suhu 56°C, suhu leburan pada 250°C, masa suntikan pada 0.7s dan masa penyejukan pada 15.4s. Hasil ANOVA menunjukkan bahawa masa penyejukan menyumbang 86.76% untuk semua tindak balas. Oleh itu, pengoptimuman multi-respon dapat meramalkan kualiti produk plastik yang dihasilkan dari proses pengacuan suntikan plastik.*

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## TABLE OF CONTENTS

	<b>PAGE</b>
<b>DECLARATION</b>	
<b>DEDICATION</b>	
<b>ABSTRACT</b>	<b>i</b>
<b>ABSTRAK</b>	<b>ii</b>
<b>ACKNOWLEDGEMENTS</b>	<b>iii</b>
<b>TABLE OF CONTENTS</b>	<b>iv</b>
<b>LIST OF TABLES</b>	<b>viii</b>
<b>LIST OF FIGURES</b>	<b>x</b>
<b>LIST OF APPENDICES</b>	<b>xii</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xiii</b>
<b>LIST OF PUBLICATIONS</b>	<b>xiv</b>
<b>CHAPTER</b>	
<b>1. INTRODUCTION</b>	<b>1</b>
1.1 Background of Study	1
1.2 Problem Statement	2
1.3 Objectives of Study	4
1.4 Significance of Study	5
1.5 Scope of Study	5
1.6 Thesis Outline	6
<b>2. LITERATURE REVIEW</b>	<b>7</b>
2.1 Introduction to Plastic Injection Moulding	7
2.1.1 Types of Injection Moulding Machine	8
2.2 Injection Moulding Parameters	11
2.2.1 Mould Temperature	15
2.2.2 Set Melt Temperature	16
2.2.3 Injection Time	18
2.2.4 Cooling Time	18
2.3 Plastic Materials	19
2.3.1 Polypropylene (PP)	20
2.4 Quality of Plastic Part	21
2.4.1 Weight of Plastic Part	22
2.4.2 Warpage of Plastic Parts	24
2.4.3 Shrinkage of Plastic Parts	26
2.4.4 Mechanical Properties of Plastic Parts	28

2.5	Computer Aided Engineering (CAE) Simulation	30
2.6	Design of Experiment (DOE)	31
2.6.1	Taguchi Method	32
2.6.2	Confirmation Run	35
2.6.3	Multi-response by Taguchi Based Grey Relational Analysis	35
2.7	Analysis of Variance (ANOVA)	38
2.8	Summary	40
<b>3.</b>	<b>METHODOLOGY</b>	<b>41</b>
3.1	Introduction	41
3.2	Plastic Part Design and Material	43
3.2.1	Plastic Part Design	43
3.2.2	Polypropylene, TITANPRO SM340	44
3.3	Experimental Equipments	44
3.3.1	Injection Moulding Machine	44
3.3.2	Mould Temperature Controller	45
3.4	Experimental Matrix	46
3.4.1	Moulding Window	46
3.4.2	Level of Parameters Design	46
3.5	Equipment for Measurement/Testing	47
3.5.1	Digital Electronic Weighing Machine	47
3.5.2	Horizontal Profile Projector	48
3.5.3	Digital Vernier Caliper	49
3.5.4	Universal Testing Machine (UTM)	50
3.6	Summary	50
<b>4.</b>	<b>RESULTS AND DISCUSSION</b>	<b>51</b>
4.1	Plastic Part Design and Moulding Window Analysis	51
4.2	Single Response of Part Weight	52
4.2.1	Effect of Process Parameters on Part Weight	53
4.2.2	Confirmation Experiment for Part Weight	56
4.2.3	Analysis of Variance (ANOVA) for Part Weight	57
4.3	Single Response of Warpage	58

4.3.1	Effect of Process Parameters on Warpage	59
4.3.2	Confirmation Experiment for Warpage	61
4.3.3	Analysis of Variance (ANOVA) for Warpage	62
4.4	Single Response of Geometrical Shrinkage	63
4.4.1	Effect of Process Parameters on Shrinkage	66
4.4.2	Confirmation Experiment for Shrinkage	67
4.4.3	Analysis of Variance (ANOVA) for Shrinkage	68
4.5	Single Response of Ultimate Tensile Strength (UTS)	69
4.5.1	Effect of Process Parameters on Ultimate Tensile Strength (UTS)	70
4.5.2	Confirmation Experiment for Ultimate Tensile Strength (UTS)	72
4.5.3	Analysis of Variance (ANOVA) for Ultimate Tensile Strength (UTS)	73
4.6	Single Response of Tensile Modulus ( $\sigma_m$ )	74
4.6.1	Effect of Process Parameters on Tensile Modulus ( $\sigma_m$ )	74
4.6.2	Confirmation Experiment for Tensile Modulus ( $\sigma_m$ )	76
4.6.3	Analysis of Variance (ANOVA) for Tensile Modulus ( $\sigma_m$ )	77
4.7	Single Response of Percentage of Elongation (%EL)	78
4.7.1	Effect of Process Parameters on Percentage of Elongation (%EL)	79
4.7.2	Confirmation Experiment for Percentage of Elongation (%EL)	81
4.7.3	Analysis of Variance (ANOVA) for Percentage of Elongation (%EL)	81
4.8	Multi-response Optimization	82
4.8.1	Preprocessing Raw Data (Normalization)	83
4.8.2	Calculation of Grey Relational Coefficient (GRC)	85
4.8.3	Calculation of Grey Relational Grade (GRG)	86
4.8.4	Analysis of Variance (ANOVA) of GRG	88
4.8.5	Final Result Based on GRG Optimum Parameter Setting	89
4.8.6	Summary of Results	90
<b>5.</b>	<b>CONCLUSION AND RECOMMENDATION</b>	<b>92</b>
5.1	Conclusion	92
5.2	Recommendations	94

**REFERENCES**

**95**

**APPENDICES**

**105**

## LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Sequence of operation for a reciprocating screw machine	10
2.2	Related review of injection moulding process parameters with four responses	13
2.3	Range of melt temperature (Goodship, 2004)	17
2.4	Plastics used in a typical car (Patil et al., 2017)	21
2.5	Taguchi orthogonal arrays (Kai and Basem, 2009)	34
3.1	PP material properties used in simulation and experiment	44
3.2	Process parameter of four factors with three levels setting	47
3.3	Experimental matrix with total of 9 runs	47
4.1	Signal to noise (S/N) ratio for part weight	54
4.2	Response table of S/N ratio for part weight	55
4.3	Comparison result of prediction and experimental confirmation test for part weight	57
4.4	The analysis of variance (ANOVA) for part weight	58
4.5	Signal to noise (S/N) ratio for warpage	60
4.6	Response table of S/N ratio for warpage	61
4.7	Comparison result of prediction and confirmation test for warpage	62
4.8	The analysis of variance (ANOVA) for warpage	62
4.9	Signal to Noise (S/N) ratio for shrinkage in gate direction	66
4.10	Response table of S/N ratio for shrinkage	67
4.11	Comparison result of prediction and confirmation test for shrinkage	68
4.12	The analysis of variance (ANOVA) for shrinkage	69
4.13	Signal to noise (S/N) ratio for ultimate tensile strength (UTS)	71
4.14	Response table of S/N ratio for ultimate tensile strength	71
4.15	Comparison result of prediction and confirmation test for UTS	72
4.16	The analysis of variance (ANOVA) for ultimate tensile strength	73

4.17	Signal to noise (S/N) ratio for tensile modulus	75
4.18	Response table of S/N ratio for tensile modulus	75
4.19	Comparison result of prediction and confirmation test for tensile modulus	76
4.20	The analysis of variance (ANOVA) for tensile modulus	77
4.21	Signal to noise (S/N) ratio for percentage of elongation	79
4.22	Response table of S/N ratio for percentage of elongation	80
4.23	Comparison result of prediction and confirmation test for percentage of elongation	81
4.24	The analysis of variance (ANOVA) for percentage of elongation	82
4.25	Summary of result from all responses	83
4.26	GRA normalized sequence after data processing	85
4.27	Grey relational coefficient (GRC)	86
4.28	Grey relational grade (GRG)	87
4.29	Response table of GRG	88
4.30	The analysis of variance (ANOVA) for grey relational grade (GRG)	89
4.31	Final results for all responses based on GRG optimum parameter setting	89
4.32	Summary results of confirmation test for single response	90
4.33	Summary results of confirmation test for multi-response	90

## LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Injection moulding machine, ARBURG (Goodship, 2004)	8
2.2	In-line reciprocating screw unit with hydraulic drive schematic (Rosato et al., 2000)	9
2.3	Two-stage screw (a) with right-angle design and (b) with parallel layup (Rosato et al., 2000)	11
2.4	Investigated process parameters in plastic injection moulding from Table 2.2	14
2.5	Investigated responses in plastic injection moulding from Table 2.2	14
2.6	Asymmetrical flow front due to different mould wall temperature (Bociaga et al., 2010)	16
2.7	Polymer structure consists of amorphous and crystalline regions (Mohammad Farhat et al., 2005)	19
2.8	Cause-and-effect diagram of main causes of defects (Bharti et al., 2010)	22
2.9	Warpage of the product (Karasu et al., 2014)	25
2.10	Fishbone diagram for warpage (Karasu et al., 2014)	25
2.11	Fishbone diagram of factors that affecting shrinkage (Annicchiarico and Alcock, 2014)	26
2.12	Tensile stress-strain curve of a thermoplastic resin (Campo, 2006)	29
2.13	An extensometer is attached to the test specimen (Campo, 2006)	30
3.1	Flowchart of the research project	42
3.2	Drawing of plastic part using CATIA software (ASTM D638)	43
3.3	Injection moulding machine	45
3.4	Mould temperature controller	45
3.5	Digital electronic weighing machine	48
3.6	Horizontal profile projector	49
3.7	Digital vernier caliper	49

3.8 Universal testing machine and extensometer	50
4.1(a) Plastic part in CATIA and (b) AMI simulation environment	52
4.2 Experimental result of part weight with standard deviation	52
4.3 S/N response diagram of part weight	56
4.4 Experimental result of warpage with standard deviation	59
4.5 S/N response diagram of warpage	61
4.6 Shrinkage direction at length (Ls) and width (Ws) direction	63
4.7 Experimental result of measured length of plastic part (gate direction)	65
4.8 Experimental result of measured width of plastic part (transverse direction)	65
4.9 S/N response diagram of shrinkage	67
4.10 Tensile stress-strain graph for trial 1 of run number 1	69
4.11 Experimental result of ultimate tensile strength	70
4.12 S/N response diagram of ultimate tensile strength	72
4.13 Experimental result of tensile modulus with standard deviation	74
4.14 S/N response diagram of tensile modulus	76
4.15 Experimental result of percentage of elongation with standard deviation	79
4.16 S/N response diagram of percentage of elongation	80
4.17 Main effects plot of GRG	88
4.18 Percentage contribution of all responses	91



## LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Dumbbell part drawing	105
B	Properties of polypropylene TITANPRO SM340	106
C	Specification of injection moulding machine Arburg	107
D	Result for all responses	109
E	Tensile test graph for each sample	113
F	Summary of percentage contribution of all responses	122

## LIST OF ABBREVIATIONS

ANOVA	-	Analysis of Variance
AMI	-	Autodesk Moldflow Insight
DOE	-	Design of Experiment
CAE	-	Computer Aided Engineering
GRA	-	Grey Relational Analysis
GRC	-	Grey Relational Coefficient
GRG	-	Grey Relational Grade
PP	-	Polypropylene
MoT	-	Mould Temperature
MeT	-	Melt Temperature
IT	-	Injection Time
CT	-	Cooling Time
S/N	-	Signal to Noise
SS	-	Sum of Squares

## LIST OF PUBLICATIONS

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# CHAPTER 1

## INTRODUCTION

This chapter describes the background, problem statement, objectives and scope of the project research. Further, the overall organization of the thesis contents is explained in this chapter.

### 1.1 Background of Study

Injection moulding process is the most commonly used method in manufacturing of plastic parts. Process parameter is one of the factors that affect the quality of plastic parts and the optimization of process parameter is one of the most important ways to minimize defects of moulded products. Traditionally, the injection moulding process parameters are determined by trial-and-error method or based on the experience of the person that handling the machine. However, this approach is time consuming and not cost effective (Rathi and Salunke, 2012). Zhao et al. (2010) stated that there is no assurance that the optimum process parameters can be obtained by using this time consuming approach.

In the past few years, numerous studies have been conducted by researchers by implementing DOE to obtain the optimum parameters setting. Barghash and Alkaabneh (2014) claimed that DOE is a very useful tool to analyze complicated industrial design problems and to understand the process characteristics. Investigations on how parameter inputs affect the output can be made based on statistical principles in the DOE. There are many processing factors are involved in injection moulding process and utilization of parameter design is needed to find optimum levels for minimization of injection defects

such as warpage, shrinkage, sink mark and many more. Therefore, DOE is crucial method to identify the significance factors that influence the output of the injection moulding process.

In order to eliminate the costly trial and error process, several researchers have conducted various type of experiment by adopting the Taguchi method as the DOE(Chandramouli and Eswaraiah, 2017; Nandagopal and Kailasanathan, 2016; Razak et al., 2016). Taguchi method is considered as an efficient and effective experimental approach that an reduce the experimental trials and able to determine the optimum level of process parameters (Kuo and Liao, 2015). Hence, it is clear that by implementing Taguchi method, trial and error approach can be avoided and cost as well as time needed to conduct experiment can be reduced at the same time.

Even though Taguchi method is widely implemented in various research areas, this method is only suitable to optimize a single response at a time and it is not applicable to optimize multi-response simultaneously (Nelabhotla et al., 2016). To overcome this problem, several researchers decided to implement multi-response optimization method called Taguchi method with GRA (Acir et al., 2017; Aravind et al., 2017; Leeba et al., 2017).

## **1.2 Problem Statement**

In plastic injection moulding industry, effective methods to reduce defects of plastic product is by controlling and adjusting process parameters. To find the optimal process parameters through experiment is very difficult and time consuming, therefore trial-and-error method is widely used (Kitayama and Natsume, 2014). This traditional trial-and-error method heavily relies on the experiences of operators (Yang et al., 2015) and no longer sufficient to meet challenges of globalization (Fei et al., 2013). In addition, Barghash and

Alkaabneh (2014) claimed that DOE is a very useful tool to analyze complicated industrial design problems and to understand the process characteristics. Investigations on how parameter inputs affect the output can be made based on statistical principles in the DOE. Compared to other DOE technique, Taguchi method only requires minimal experimental runs for process optimization and through this method, it is possible to avoid the trial-and-error methods and able to reduce the experimental costs needed to achieve a stable and high quality process (Jou et al., 2014).

There are many process parameters involved in injection moulding such as mould temperature, melt temperature, cooling temperature, melt pressure, injection time, filling time, packing time, holding time, cooling time, injection rate and many more (Kashyap and Datta, 2015). The processing factors in injection moulding process greatly influence the quality of final products. In addition, the development of computer simulation is aimed to mimic the injection moulding process and replace the expensive, time-consuming through trial-and-error method (Mukras and Al-Mufadi, 2015). Therefore, the molding window analysis in Moldflow software is used to get the range of recommended process parameters for plastic parts (Deng et al., 2010). Furthermore, the molding window analysis is performed to evaluate optimum conditions and improve the manufacturability of the part (Khan et al., 2014).

In addition, minimization of defects in plastic products is important to meet the quality requirement of plastic products. There are many types of plastic part quality involved in injection moulding process. One of the plastic qualities is part weight because it is claimed as an important indicator quality of moulded products (Zhang et al., 2015). Moreover, part weight is strongly related with the mechanical behavior of plastic parts (López et al., 2016). In addition, warpage of plastic parts become a major defects in the injection moulding process (Santos et al., 2015). Warpage optimization is important

especially in assembly process because it can cause structural unfitness (Wu et al., 2011). Besides warpage, shrinkage minimization of plastic parts is needed to reduce difference between mould design and final specimen dimensions especially in applications that require tight tolerances (Annicchiarico and Alcock, 2014). During injection moulding process, plastic shrinkage varies on processing parameters, gate location, plastic type and product structure. Different gate locations have a significant influence on shrinkage of plastic parts because it affects the orientation and crystallization of the polymer chains (Fangcheng et al., 2013). Furthermore, the direction of plastic shrinkage also is investigated by considering shrinkages parallel to and normal to the direction of plastic melt flow (Postawa and Koszkuł, 2005; Kusić et al., 2013; Cadena-Perez et al., 2015). For plastic strength, numerous investigations have been conducted because mechanical properties play an important role to determine the quality of moulded parts (Mirvar et al., 2011) and it is greatly affected by process parameters (Dar et al., 2016).

Even though Taguchi method is often selected as DOE method, this technique is limited to optimize single quality performance only and it is not suitable to optimize multiple responses simultaneously (Nelabhotla et al., 2016). Therefore, several researchers decided to overcome this problem by implementing multi-response optimization method called Taguchi method with GRA (Acir et al., 2017; Aravind et al., 2017; Leeba et al., 2017; Seenuvasaperumal and Elayaperumal, 2017; Shinde and Pawar, 2017).

### **1.3 Objectives of Study**

The main objective of this study is to optimize injection moulding process parameters using single and multi-response Taguchi method with Grey Relational Analysis (GRA). To achieve the main objective, three sub objectives are stated as follows:

- i. To investigate the effect of process parameters such as mould temperature, melt temperature, injection time and cooling time on all responses such as part weight, warpage, geometrical shrinkage and mechanical properties of plastic parts.
- ii. To optimize single responses such as part weight, warpage, shrinkage and mechanical properties of plastic parts by using Taguchi method.
- iii. To optimize multi-responses such as part weight, warpage, shrinkage and mechanical properties of plastic parts by using Taguchi method with Grey Relational Analysis (GRA).

#### **1.4 Significance of Study**

This project is to determine one set of optimum parameters such as mould temperature, melt temperature, injection time and cooling time on multi-response. The quality of multi-response can be predicted with the one set of parameters. By using multi-response optimization of GRA, industrial practitioners can practice this method to minimize defects on plastic products.

#### **1.5 Scope of Study**

This research focuses on optimization of injection moulding process parameters by using single and multi-response Taguchi method with GRA. Injection moulding machine Arburg model 370H 600-170, 60 tonnage was used to conduct the experiment in this research. Injection moulding parameters that have been investigated were mould temperature, melt temperature, injection time and cooling time. The studied responses were part weight measured by using digital electronic weighting machine, warpage using Mitutoyo horizontal optical comparator model PH 3500, shrinkage using Mitutoyo digital caliper and mechanical properties tested by using Universal Testing Machine (UTM)