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

NOORFA IDAYU BINTI MOHD ALI

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

NOORFA IDAYU BINTI MOHD ALI

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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.

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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	:……………………….
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DEDICATION

To my beloved family members.

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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 factorsare 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 elongationwere studied. The parameters involved in this study weremould temperature, melt temperature, injection time and cooling time. Taguchi methodwas used where L9 with nineruns 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 responsefor part weight is the mould temperature which contributes 58.88%. Meanwhile, for warpage, melt temperature contributes 38.96%. For shrinkage, mould temperaturecontributes 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 temperaturecontribution is 51.41%. Multi-response optimization shows that a set of input parameters for all responses are mould temperature at 56^{o}C, melt temperature at 250^{o}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 producedin plastic injection moulding process.

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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^{o}C, suhu leburan pada 250^{o}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

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LIST OF TABLES

© Universiti Teknikal Malaysia Melaka

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LIST OF FIGURES

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LIST OF APPENDICES

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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

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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 tominimize 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

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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 (Acır et al., 2017; Aravind et al., 2017; Leeba et al., 2017).

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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

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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 weightis 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

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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 Koszkul, 2005; Kusić et al., 2013; Cadena-Perez et al., 2015). For plastic strength,numerous investigations have been conducted because mechanical properties playan 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(Acır 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 withGrey Relational Analysis (GRA). To achieve the main objective, threesub objectives are stated as follows:

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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 responsesuch as part weight, warpage, shrinkage and mechanical properties of plastic parts by using Taguchi method.

iii. To optimize multi-responsesuch 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 withGRA. 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)

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