

**ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY**

**School of Mechanical, Chemical and Materials Engineering**

**Program of Manufacturing Engineering**



**A Thesis Submitted in Partial Fulfillment of the  
Requirement for the Degree of  
Masters of Science in Manufacturing Engineering**

**Optimization of Process Parameters in Plastic Injection  
Molding Machine Using Design of Experiment Method; a Case  
Study on Ameze Plastic Factory**

**Name-Minyahil Bezabih**

**ID N<sup>o</sup> -GSR/0104/09**

**Advisors- Dr. Perumulla Janaki Ramulu and  
Dr. Habtamu Beri**

**June 2018**

**Adama, Ethiopia**

**Adama Science and Technology University**

**School of Mechanical, Chemical and Materials Engineering**

**Program of Manufacturing Engineering`**



**Optimization of Process Parameters in Plastic Injection Molding Machine Using Design of Experiment Method; a Case Study on Ameze plastic Factory**

<b>Name</b>	<b>ID No</b>	<b>Signature</b>
1. Minyahil Bezabih	GSR/0104/09	_____

**Approved by Board of Examiners**

_____	_____	_____
Advisor	Signature	Date
_____	_____	_____
Co Advisor	Signature	Date
_____	_____	_____
Chairperson	Signature	Date
_____	_____	_____
Internal Examiner	Signature	Date
_____	_____	_____
External Examiner	Signature	Date

## **Declaration**

I hereby, declare this research work on “**Optimization of process parameters in plastic injection molding machine using design of experiment method; case study on Ameze plastic factory**” is the result of my own confident work and that all source of materials used in this work have been duly acknowledged. This research work submitted in partial fulfillment of the requirement for the degree of Masters Science in Manufacturing Engineering at Adama Science and Technology University, Adama, and it is deposited at University Library to be made available to borrower under rule of the library. I solemnly declare that this is not submitted to any other institution/University anywhere for the award of any academic degree, publication, or certificate.

Name	ID No	Signature
Minyahil Bezabih	GSR/0104/09	_____
Advisor	Signature	Date
Dr. Perumalla Janaki Ramulu	_____	_____
Advisor	Signature	Date
Dr.Habtamu Beri	_____	_____

Place: Adama Science and Technology University, Adama Ethiopia.

Date of submission: \_\_\_\_\_

## **Acknowledgement**

First, a lot blessing and thanks to my Almighty GOD for giving me the ability and wisdom to do this project successfully. Then, I would like to thanks my adviser Dr. Perumalla Janaki Ramulu (Associate Professor), and co advisor Dr. Habtamu beri (Assistant Prof) in program of Design and Manufacturing Engineering at Adama Science and Technology University, for there progressive support, advice, initiate and guidance to do this research work.

In addition, I would like to thank Ameze plastic factory, all staff members and technicians of Ameze plastic factory specially Mr. Dajana for giving his support to do this work successfully.

I would like to give a gratefully acknowledgement to Adama Science and Technology University for financial support in academic and research work. I am also grateful acknowledged to academic staff of Adama Science and Technology University to support and advise me in this work.

Finally, I would like to thank our families for understanding and supporting me.

## **Abstract**

Plastic injection molding is one of the most well-known method of processing plastic materials in to different complex shapes and sizes. Thermoplastic materials have light weight, low cost, low environmental impact and easily reprocessed due to this reason, they are more preferable in production of different equipments. The aim of this research was to study about optimization of plastic injection molding process parameters to reduced flash and short shot defects on the plastic products in Ameze plastic factory. The experimental investigation were carried out, using Taguchi method L27 orthogonal array in Minitab17. The selected process parameters of Plastic injection molding machines are melting temperature, holding pressure, injection pressure, injection speed and cooling time. Signal-to-noise (S/N) ratio and Analysis of Variance (ANOVA) were used to find the optimum setting and significant factors of plastic injection molding process. According to the results, the optimal parameter setting for minimizing flash defect are melting temperature 250°C, holding pressure 63MPa, injection pressure 84MPa, injection speed 70rpm and cooling time 45sec and short shot defect are melting temperature 270°C, holding pressure 84MPa, injection pressure 84MPa, injection speed 70rpm and cooling time 65sec. the result shows that flash defect are reduced by 7.07% and short shot defect of rejection the finishing product reduced by 6%. The experimental results shows good conformity to reduced flash and short shot defect in plastic injection molding machine products in Ameze plastic factory.

**Keywords;** *Flash, short shot, Plastic injection molding machine and Taguchi method.*

## **Table of Contents**

DECLARATION.....	ii
ACKNOWLEDGEMENT.....	iii
ABSTRACT.....	iv
TABLE OF CONTENTS.....	v
LIST OF TABLES.....	viii
LIST OF FIGURES.....	ix
NOMENCLATURE.....	xi
CHAPTER ONE.....	1
INTRODUCTION.....	1
1.1 Background of the study.....	1
1.2 Background of the company.....	2
1.3 Statement of the problem.....	2
1.4 Objectives.....	3
1.4.1 General objective.....	3
1.4.2 Specific objectives.....	3
1.5 Scope of the research.....	3
1.6 Research question.....	3
1.7 Methodology.....	4
1.8 Outline of the thesis.....	4
CHAPTER TWO.....	5
LITERATURE REVIEW.....	5
2.1 Introduction.....	5
2.2 Polymers and their classification.....	5
2.2.1 Classification of polymer based on molecular structure.....	6
2.2.2 Classification of polymer based on reaction to temperature.....	8
2.3 Copolymers.....	9

2.3.1. Alternative copolymer .....	9
2.3.2. Random copolymer .....	9
2.3.3. Block copolymer .....	9
2.3.4. Graft copolymer .....	10
2.4 Mechanical behavior of polymers .....	10
2.5 Polypropylene (PP).....	12
2.5.1 Advantages of polypropylene .....	13
2.5.2 Disadvantages and limitations of polypropylene.....	13
2.5.3 Typical applications of polypropylene .....	13
2.6 Injection molding process.....	14
2.7 Process description .....	16
2.8 Design of experiments .....	17
2.9 Taguchi methods .....	18
2.9.1 Taguchi philosophy.....	18
2.9.1.1 System design: .....	19
2.9.1.2 Parametric design:.....	19
2.9.1.3 Tolerance design .....	19
2.9.2 Achieving quality -taguchi's seven points.....	19
2.9.3 Definition and measurement of quality .....	20
2.9.4 Performance statistics and optimization using signal to noise ratio .....	21
2.10 Related research literatures.....	23
2.11 Motivation .....	28
CHAPTER THREE.....	29
MATERIALS AND METHODS .....	29
3.1 Introduction .....	29
3.2 Plastic material .....	29
3.3 Injection molding machine .....	31

3.4 Experimental measuring instrument .....	32
3.5 Experimental method .....	33
3.6 Experimental design .....	35
CHAPTER FOUR .....	37
RESULTS AND DISCUSSION.....	37
4.1 Introduction.....	37
4.2 Failure mode analysis .....	37
4.3 Cause and effect.....	41
4.4 Taguchi orthogonal array result .....	43
4.5 Analysis of variance.....	49
4.6 Confirming experiment.....	50
CHAPTER FIVE .....	54
CONCLUSIONS AND RECOMMENDATIONS.....	54
5.1 Conclusions.....	54
5.2 Recommendations and Future work .....	55
REFERENCES .....	56
APPENDIX .....	59

## **List of Tables**

Table 2.1 Some More Common Polymers. (Callister, 2001).....	12
Table 2.2 General property of polypropylene (Campo, 2006).....	13
Table 3.1 Material characteristic of polypropylene material .....	30
Table 3.2 TIANJIAN plastic injection molding machine specification 7800.....	31
Table 3.3 TIANJIAN plastic injection molding machine specification P 10,000.....	31
Table 3.4 Orthogonal array L 27 .....	36
Table 4.1 Failure Mode Effect Analysis (FMEA) of plastic injection molding machine....	37
Table 4.2 Injection molding process parameter for polypropylene .....	42
Table 4.3 Injection molding machine parameters and their levels.....	43
Table 4.4 Taguchi orthogonal array result for flash defect .....	43
Table 4.5 Flash defect response table for S/N ratio (smaller is Better) .....	44
Table 4.6 Flash defect response table for main ratio (smaller is Better).....	44
Table 4.7 Taguchi orthogonal array result for short shot.....	46
Table 4.8 Short shot response Table for S/N ratio (smaller is Better) .....	47
Table 4.9 Short shot Response Table for main ratio (smaller is Better) .....	47
Table 4. 10 Analysis of variance for flash defect.....	49
Table 4.11 Analysis of variance for short shot defect.....	50

## **List of Figures**

Figure 2.1 Representation of long chain polymer .....	5
Figure 2.2 Representation of linear polymer .....	6
Figure 2.3 Representation of branched polymers .....	7
Figure 2.4 Representation of cross-linked polymer.....	7
Figure 2.5 Representation of network polymers .....	8
Figure 2.6 Structure of both crystalline and amorphous regions in polymer .....	9
Figure 2.7 Types of copolymers: .....	10
Figure 2.8 The stress–strain behavior for brittle polymers.....	11
Figure 2.9 Typical screw-injection molding machine .....	15
Figure 2.10 Sequence of events during a typical injection molding cycle:.....	15
Figure 2.11 conventional injection molding process.....	17
Figure 2.12 General model of a process/system.....	18
Figure 2.13 the relationship between quality loss and performance deviation from Target. .....	21
Figure 3.1 Polypropylene material p640J.....	29
Figure 3.2 TIANJIAN plastic injection molding machine PL 7800.....	31
Figure 3.3 TIANJIAN plastic injection molding machine PL 10,000.....	32
Figure 3.4 F1976 Digital weight measurement .....	32
Figure 3.5 Flowchart of methodology .....	34
Figure 4.1 Flash defect on laundry bucket.....	41
Figure 4.2 short shot on laundry bucket. ....	41
Figure 4.3 Fishbone diagram of plastic injection molding machine parameters.....	42
Figure 4.4 Flash defect main effect plot for S/N ratio.....	44
Figure 4.5 Flash defect main effect plot for means .....	45
Figure 4.6 Short shot main effect plot for S/N ratio.....	47
Figure 4.7 Short shot defect main effect plot for means .....	48
Figure 4.8 Pie chart shows flash defect on plastic injection machine before optimal setting is set.....	51
Figure 4.9 pie chart of flash defect on plastic injection molding machine after optimal setting is set .....	51
Figure 4.10 Pie chart shows short shot defect on plastic injection machine before optimal setting is set. ....	52

Figure 4.11 Pie chart shows short shot defect on plastic injection machine after optimal setting is set..... 52

## **Nomenclature**

Adj ss	Adjusted sum of squares
Adj ms	Adjusting sum of square
ANOVA	Analysis of variance
CQI	Continuous quality improvement
C.T	Cooling time
DF	Degree of freedom
DOE	Design of experiment
F	F-Ratio
FMEA	Failure Mode Effect Analysis
H.P	Holding pressure
I.P	Injection pressure
I.S	Injection speed
M.T	Melting temperature
OA	Orthogonal array
PIM	Plastic injection molding
PP	Polypropylene
P	Significance level
Seq ss	Sequential sum of squares
S/N	Signal to noise ratio



# **CHAPTER ONE**

## **INTRODUCTION**

### **1.1 Background of the study**

Manufacturing is transforming raw materials in to useful products. The transformation process requires science to transfer raw material to finished product, knowledge of material and optimization technique to get exact target product quality. To produce products with high quality and low cost, well organized technique, knowledge and skill are required.

Plastic injection molding is one of the most well-known method of processing plastic materials in to different complex shapes and sizes. Many special processes have been developed during last decades in order to improve injection molding capabilities but basic procedure is well-known for industrial companies (Lopez et al, 2016). The same author revealed that, to produce conventional plastic parts, it is necessary to use raw material, mold, and injection machine which introduces the melt material inside the mold. Each part is manufactured by means of an injection cycle composed of three basic stages: filling, Packing and cooling.

Recently, sustainable usage of materials is getting an attention of manufacturers due to economic, social and environmental problems. Sustainable usage of materials at optimum levels requires optimization tools like design of experiments. “Design of Experiment is a statistical technique used to study multiple variables (also called factors or parameters) simultaneously (Antony, 2003). It study about the relation between factors and response to get better quality of products. The advanced part of design of experiment is called “The Taguchi approach” which was developed by Genichi Taguchi, as series of experiments that resembled partial factorial designs and featured orthogonal arrays. “Orthogonal Arrays” (OA) provide a set of well-balanced (minimum) number of experiments serve as objective function for optimization (C.Montgomery, 2001).

Process parameters during PIM were mostly relied on the technicians’ personal experience in the past. Although a better combination of process parameters can be found with the help of the computer numerical simulation technology nowadays, it is still hard to find the optimum combination of the processing parameters accurately and quickly.

This paper examine optimization of process parameters in plastic injection molding machine to reduce flash and short shot defects in a case of Ameze plastic factory. The problems

associated with injection molding process were happened due to improper selection of process parameters and this leads to low quality of products, rework, materials loss and reduction of production rate. Such parameters include melting temperature, holding pressure, injection pressure, injection speed and cooling time. Proper selection of such variables is critical for achieving defect free and high quality products in plastic injection molding machine. To minimize flash and short shot defects on plastic injection molding process Taguchi method is employed. The determination of optimal process parameters is based on S/N and main ratio.

Organization of this paper work have the following stapes: collect sample data on flash defects, select control factor and its level. Select proper orthogonal array design, conduct the experiment, analyzed the result of the experiment, identify the significant factor using ANOVA and confirmation of the experiment.

## **1.2 Background of the company**

Ameze plastic factory is one of the sisters companies of Aleta Land business group and established in 2006 E.C at South Nation Nationalist People Republic regional state. The factory has been established with capital of 33,000,000 million Ethiopian birr and now a days, its capital is increased to 55 Million Ethiopian birr. This factory produces different house hold plastic products such as laundry buckets, chairs, stools, different kind of baskets, small and big jogs, small and medium basin, polybags and etc. The companies have 80 workers and has its own management structure that leads to the overall function of the factory. Management structure of the company consists of General Manager, regional manager, factory manager and other professions.

## **1.3 Statement of the problem**

Process parameter of injection molding machine have influence on the quality and cost of product. Unsystematic selection of process parameters causes defects on plastic injection molding machine product. In Ameze plastic factory trial and error method was applied on injection molding machine to get better quality of product. However, this method is not effective due to unnecessary experiments run, time consumed and does not show the interaction between factors.

Flash and short shot defects are common in plastic products of injection molding machine. This is due to improper selection of process parameters and causes material wastage, rejection, increase the cost of product, loss of attractiveness of products and unnecessary

labor time. In order to optimize loss in plastic injection molding machine it is necessary to investigation on the process parameters like injection time, holding time, cooling time melt temperature, mold temperature, injection pressure and holding pressure and etc. Optimal selection of such variables are key for achieving defect free and high quality product on plastic molding machine at Ameze plastic factory.

## **1.4 Objectives**

### **1.4.1 General objective**

The main aim of this research is to optimize the process parameters of plastic injection molding process using design of experiment techniques to reduced flash and short shot defect.

### **1.4.2 Specific objectives**

The specific objectives of this research are as follows:

- To identify the critical defects of plastic injection molding machine.
- To identify the control factors of plastic injection molding process and their levels.
- To conduct the experiment based on orthogonal array process parameter combination.
- To analyze the result of the experiment.

## **1.5 Scope of the research**

This research work is delimited to the optimization of process parameters of plastic injection molding process to reduce flash and short shot defects. The approach taken was to use design of experiment and failure mode analysis in plastic injection molding machine. For experimental investigation, Taguchi Orthogonal array L27 was employed. This study is focused on one company I.e. Ameze plastic factory only, as a result, a single case study research strategy is employed.

## **1.6 Research question**

This paper examined the following questions in Ameze plastic factory

1. What are the critical defects exist in plastic injection molding machine?
2. What are the major process parameter that subjected to defects?
3. What measurement should be taken to reduce this defects?
4. What are the optimum parameters setting should be assigned for each process in order to eliminate defects on plastic injection molding machine?

## **1.7 Methodology**

In order to get the optimum parameters on plastic injection molding machine to produced defect free product the following procedures are considered

- ✓ Selected defects on plastic injection molding machine.
- ✓ Selected proper design of experiment method.
- ✓ Selected control factors and its level.
- ✓ Choose orthogonal array.
- ✓ Run experiment.
- ✓ Analyzed the result of the experiment.
- ✓ Confirmed the experiment.

## **1.8 Outline of the thesis**

**Chapter one** present about general overview, introduction, statement of the problem, objective i.e. general objectives and specific objectives, significance of the thesis, scope of the thesis, research questions, methodology and outline of the thesis. **Chapter two** present about General overview, Polymer and its Classification, Copolymer, Mechanical behavior of Polymers, Polypropylene, Plastic injection molding machine, Process description of plastic injection molding machine, Design of Experiment, Taguchi methods, Definition and measurement of quality, Performance statistics ,ANOVA and related work. **Chapter three** present about general overview, materials and methods this include plastic material, injection molding machine and experimental measuring instrument, experimental procedure, cause and effect and experimental design. **Chapter four** present about general overview, Experimental result of Taguchi Orthogonal array analysis of variance and confirmation of the experiment. **Chapter five** present about general overview, conclusion and recommendation and future work.

## CHAPTER TWO

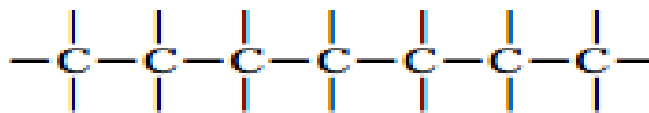
### LITERATURE REVIEW

#### 2.1 Introduction

Precision manufacturing of plastic injection molding machine product requires knowledge of polymer material, injection molding process and optimization technique. This chapter focused on polymer and its classification, copolymer, mechanical behavior of polymer, polypropylene, injection molding, process description of injection molding, design of experiment, Taguchi methods, definition and measurement of quality, performance statistics and signal to noise ratio, related work and motivation.

#### 2.2 Polymers and their classification

Naturally occurring polymer those derived from plants and animals have been using for many centuries; these materials include wood, rubber, cotton, wool, leather, and silk. Other natural polymers such as proteins, enzymes, starches, and cellulose are important in biological and physiological processes in plants and animals. Modern scientific research tools have made possible determination of the molecular structures of this group of materials, and the development of numerous polymers, which are synthesized from small organic molecules. Many of our useful plastics, rubbers, and fiber materials are synthetic polymers. For the most polymers, these molecules are in the form of long and flexible chains, the backbone of which is a string of carbon atoms; many times each carbon atom singly bonds to two adjacent carbons atoms on either side, represented schematically in two dimensions as follows in Figure 2.1 (Callister, 2001).



**Figure 2.1 Representation of long chain polymer (Callister, 2001)**

The long chain of atoms is called polymer, the polymer is formed by building them up from many very small units or individual group called monomers, joining single units. (Strong, 2006). “**Mer**” originates from the Greek word **meros**, which means part; the term polymer was coined to mean many mers. Sometimes use the term **monomer**, which refers to as single molecule from which a polymer is synthesized. Each of the two remaining valence electrons for every carbon atom may be involved in side bonding with atoms or radicals that are

positioned adjacent to the chain. Of course, both chain and side double bonds are possible. These long molecules are composed of structural entities called “Mer” units, which are successively repeated along the chain (Callister, 2001).

### **2.2.1 Classification of polymer based on molecular structure**

The physical characteristics of a polymer depend not only on its molecular weight and shape, but also on differences in the structure of the molecular chains. Modern polymer synthesis techniques permit considerable control over various structural possibilities. This section discusses several molecular structures including linear, branched, cross linked, and network, in addition to various isomeric configurations. (Callister, 2001).

#### **2.2.1.1 Linear polymers**

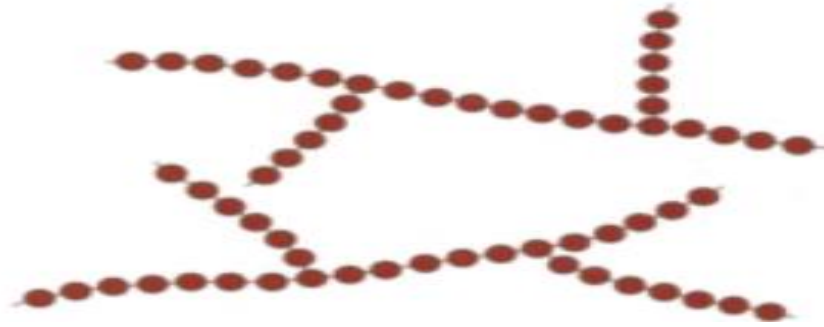
Linear polymers are those in which the “Mer” units are joined together end to end in single chains. These long chains are flexible and may be thought of as a mass of spaghetti, as represented schematically in Figure 2.2, where each circle represents a “Mer” unit. For linear polymers, there may be extensive van der Waals and hydrogen bonding between the chains. Some of the common polymers that form with linear structures are polyethylene, polyvinyl chloride, polystyrene, polymethyl methacrylate, nylon, and the fluorocarbons (Callister, 2001).



**Figure 2.2 Representation of linear polymer (Callister, 2001)**

#### **2.2.1.2 Branched polymers**

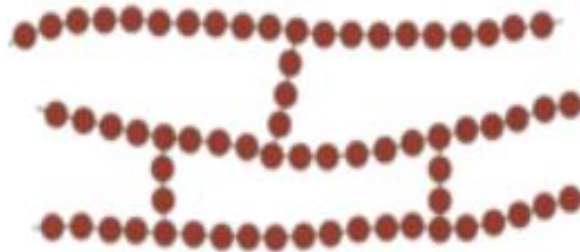
Polymers may be synthesized in which side-branch chains are connected to the main ones, as indicated schematically in Figure 2.3 these are called branched polymers. The branches, considered to be part of the main-chain molecule, result from side reactions that occur during the synthesis of the polymer. The chain packing efficiency is reduced with the formation of side branches, which results in a lowering of the polymer density. Those polymers that form linear structures may also be branched (Callister, 2001).



**Figure 2.3 Representation of branched polymers (Callister, 2001)**

### **2.2.1.3 Cross-linked polymers**

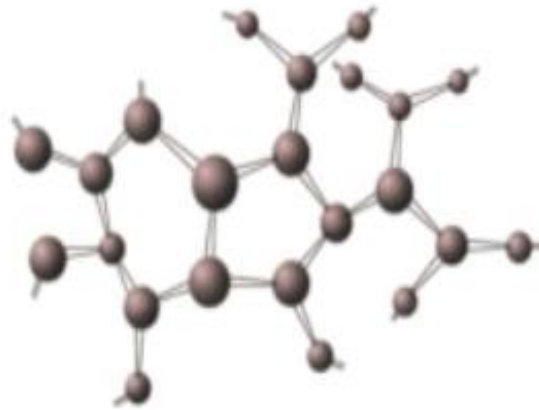
In cross-linked polymers, adjacent linear chains are joined one to another at various positions by covalent bonds, as represented in Figure 2.4. The process of crosslinking is achieved either during synthesis or by a nonreversible chemical reaction that is usually carried out at an elevated temperature. Often, additive atoms or molecules that are covalently bonded to the chains accomplish this crosslinking. Many of the rubber elastic materials are cross-linked; in rubbers, this is called vulcanization. (Callister, 2001)



**Figure 2.4 Representation of cross-linked polymer (Callister, 2001)**

### **2.2.1.4 Network polymers**

Trifunctional “Mer” units, having three active covalent bonds, form three-dimensional networks as shown in Figure 2.5 and are termed network polymers. Actually, a polymer that is highly cross-linked may be classified as a network polymer. These materials have distinctive mechanical and thermal properties; the epoxies and phenol-formaldehyde belong to this group. (Callister, 2001).



**Figure 2.5 Representation of network polymers (Callister, 2001)**

## **2.2.2 Classification of polymer based on reaction to temperature**

Polymer are classified based on reaction to temperature as thermoplastic and thermoset.

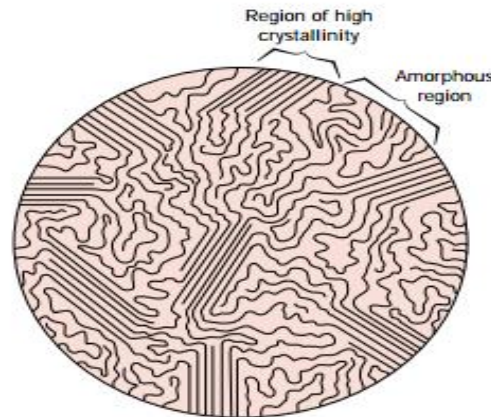
### **2.2.2.1 Thermoplastic**

Thermoplastic is polymer would soften upon heating and could then be made to flow when a stress was applied. When cooled again, they would reversibly regain their solid or rubbery nature (Stephen, 1993). Thermoplastic polymer were composed of long chains produced by joining small molecules, or monomer; they behave in a plastic, flexible manner. These polymers soften and are formed by viscous flow when heated to elevated temperature (Askeland, 1998). Thermoplastics are divided into two main classes, amorphous and crystalline (Gordon, 2010).

**2.2.1.1.1 Amorphous plastics** do not have a sharp melting point. When subjected to increasing temperature, they soften and begin to puddle. They have lower physical properties, which rapidly fall off as temperature increases. They are very resistant to impact loads because of their molecular structure versus thermosets (Gordon, 2010).

#### **2.2.1.1.2 Crystalline Plastics**

Crystalline polymers have a sharp melting temperature. They remain solid until that temperature is reached and then melt like an ice cube from the outside to the center. They behave like an amorphous polymer in the molten stage but usually have a higher flow rate. On cooling, they have much greater mold shrinkage because of the degree of crystallinity of the polymer as shown in Figure 2.6 (Gordon, 2010).



**Figure 2.6 Structure of both crystalline and amorphous regions in polymer (Callister, 2001)**

### **2.2.2.1 Thermosets**

Thermosets is other branch of polymer although they might be heated to the point where they would soften and could be made to flow under stress once, would not do so reversibly; that is heating caused them to undergo a “curing” reaction (Stephen, 1993). Thermosetting polymer are composed of long chain of molecules that are strong crosslink to one another to form three-dimensional networked structure. These polymers are generally more rigid, strong, but more brittle than thermoplastic. Thermosets do not have a fixed melting temperature and cannot easily be reprocessing after the cross-linking reaction has occurred. (Askeland, 1998)

## **2.3 Copolymers**

When two or more kinds of mars are mixed within a single polymer chain then copolymers are produced. (Ohring, 1995). Polymer with mixed monomers are called copolymers, and they are characterized as having more than one types of repeat unit. (Strong, 2006).

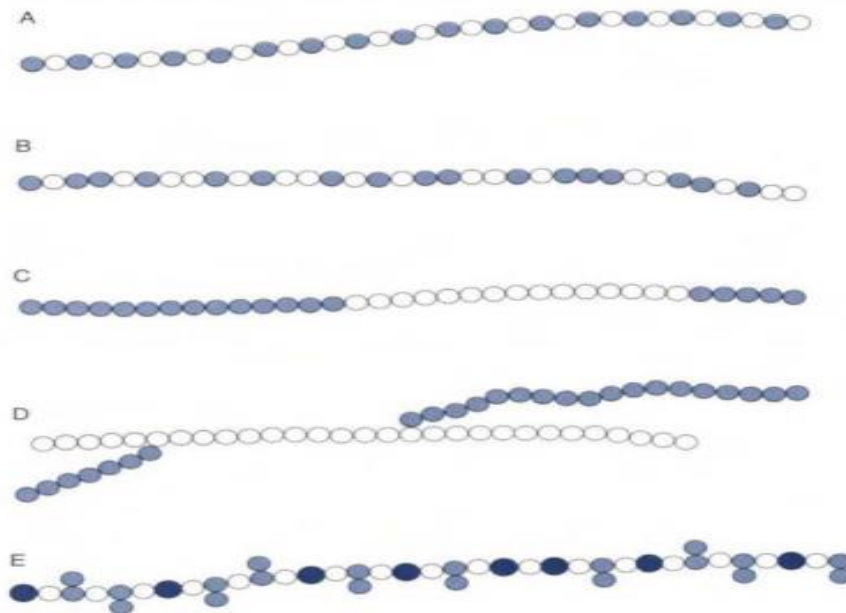
**2.3.1. Alternative copolymer** pattern, as shown in Figure 2.7. this pattern the monomer have regular ,alternative sequence which can be represent as X-Y-X-Y, etc. (Strong, 2006).

**2.3.2. Random copolymer** the mixture of monomer can produced a random co polymer structure as shown in Figure 2.7, where there is no pattern in the order of the monomers along the polymer chain (Strong, 2006).

**2.3.3. Block copolymer** this type of copolymer pattern occurs when long sequences of one monomer join long sequence of the other monomer to form the chain as shown in Figure 2.7. This pattern is characterized by several monomer of one type in a row along the backbone

followed by several monomers of the second type, also along the backbone such as X-X-X-X-Y-Y-Y-Y-X-X-X-X-X etc. (Strong, 2006).

**2.3.4. Graft copolymer** as shown in Figure 2.7, this type of copolymer, a polymer chain is formed by one monomer (X) and then a chain of the other monomer (Y) is attached as a branch to the main backbone (Strong, 2006)

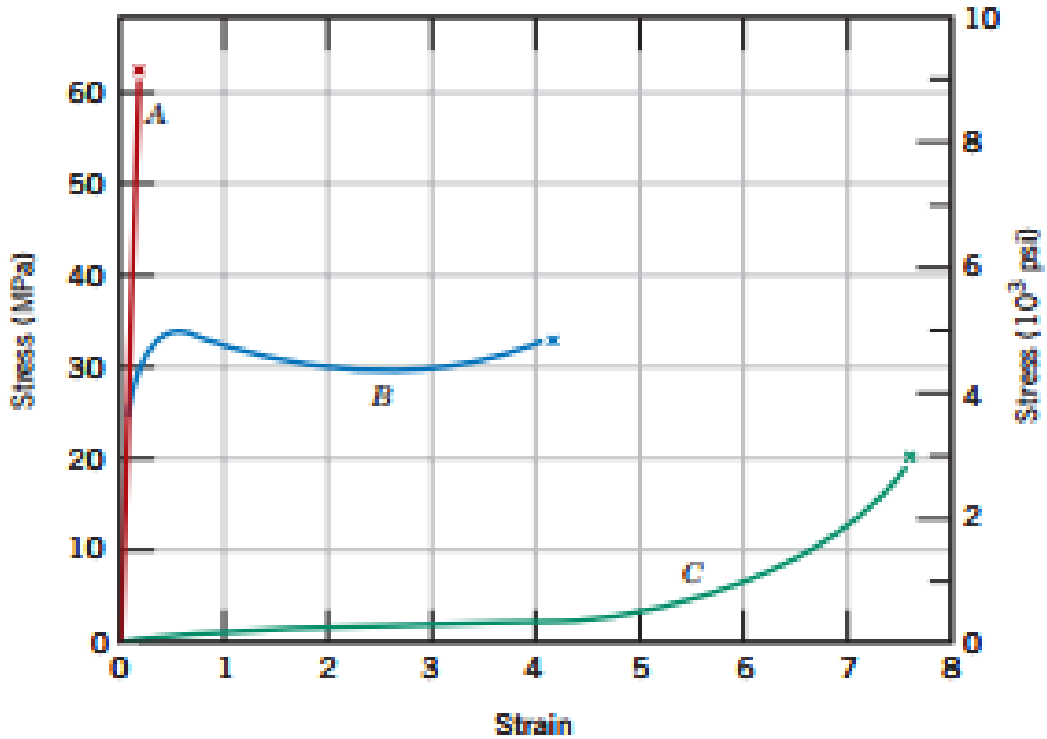


**Figure 2.7 Types of copolymers:**

**(A) Alternating. (B) Random. (C) Block. (D) Graft. (E) Ter-polymers (Ohring, 1995).**

## **2.4 Mechanical Behavior of Polymers**

The mechanical properties of polymers are specified with many of the same parameters that are used for metals that is, modulus of elasticity, and yield and tensile strengths. For many polymeric materials, the simple stress-strain test is employed for the characterization of some of these mechanical parameters. The mechanical characteristics of polymers, for the most part, are highly sensitive to the rate of deformation (strain rate), the temperature, and the chemical nature of the environment (the presence of water, oxygen, organic solvents, etc.).



**Figure 2.8** The stress–strain behavior for brittle (curve A), plastic (curve B), and highly elastic (elastomeric) (curve) polymers (Callister, 2001)

Three typically different types of stress–strain behavior are found for polymeric materials, are represented in Figure 2.8. Curve A illustrates the stress–strain character for a brittle polymer, inasmuch as it fractures while deforming elastically. The behavior for a plastic material, curve B is similar to that for many metallic materials; the initial deformation is elastic, which is followed by yielding and a region of plastic deformation. Finally, the deformation displayed by curve C is totally elastic; this rubber-like elasticity (large recoverable strains produced at low stress levels) is displayed by a class of polymers termed the elastomers (Callister, 2001). Mechanical characteristics of some of the more common polymers at room temperature are shown in Table 2.1.

**Table 2.1 Some More Common Polymers. (Callister, 2001)**

<b>Material</b>	<b>Specific gravity</b>	<b>Tensile Modulus (GPa)</b>	<b>Tensile Strength (MPa)</b>	<b>Yield Strength (MPa)</b>	<b>Elongation at Break (%)</b>
Polyethylene (low density)	0.917–0.932	0.17–0.28	8.3–31.4	9.0–14.5	100–650
Polyethylene (high density)	0.952–0.965	1.06–1.09	22.1–31.0	26.2–33.1	10–1200
Poly(vinyl chloride)	1.30–1.58	2.4–4.1	40.7–51.7	40.7–44.8	40–80
Polytetrafluoroethylene	2.14–2.20	0.40–0.55	20.7–34.5	-	200–400
Polypropylene	0.90–0.91	1.14–1.55	31–41.4	31.0–37.2	100–600
Polystyrene	1.04–1.05	2.28–3.28	35.9–51.7	-	1.2–2.5
Poly(methyl methacrylate)	1.17–1.20	2.24–3.24	48.3–72.4	53.8–73.1	2.0–5.5
Phenol-formaldehyde	1.24–1.32	2.76–4.83	34.5–62.1	-	1.5–2.0
Nylon 6,6	1.13–1.15	1.58–3.80	75.9–94.5	44.8–82.8	15–300
Polyester (PET)	1.29–1.40	2.8–4.1	48.3–72.4	59.3	30–300
Polycarbonate	1.20	2.38	62.8–72.4	62.1	110–150

## 2.5 Polypropylene (PP)

Polypropylene was introduced in the late 1950s and is the fastest growing commodity thermoplastic in the world. It is a versatile polymer used in applications from fibers, films, appliances, to automobile bumpers. Polypropylene continues to displace other materials, such as fiberglass, mineral reinforced thermoplastics and metals, in a variety of applications. Polypropylene is manufactured by polymerizing propylene monomer with a titanium based catalyst, a second co-catalyst (tri ethyl aluminum) is added to initiate the polymerization reaction and hydrogen is used in the reactor to control polymer molecular weight. This reaction is produced using a slurry or gas phase type of process. There are three PP structures: isotactic, syndiotactic, and a tactic. The principal structure of PP is isotactic semi-crystalline in a helical form. This structure has good mechanical properties, such as stiffness and tensile strength. These properties can be further increased with nucleating agents or with fillers, such as talc, calcium carbonate, or fiberglass (Campo, 2006). General property of polypropylene material as shown in table 2.2.

**Table 2.2 General property of polypropylene (Campo, 2006)**

General properties of generic unfilled pp homo polymer	
Specific gravity	0.90
Tensile modulus @ 23 °C (MPa)	0.17
Tensile strength @ yield (MPa)	4.00
Notch izod impact @ -5 °C(Ft-lb/in)	0.5–18.0
Thermal limits Service temperature. (°C)	100
Shrinkage (%)	0.5–2.0
Vicar point (°C)	160
Temperature (°C)	165–170
Humidity (°C) @ 1.82 MPa	49–60
Process temperature. (°C)	199–273
Mold temperature. (°C)	29–80
Drying temperature. (°C)	80
Drying time (sec)	7200–10,800

### 2.5.1 Advantages of Polypropylene

- Lighter or low-density polymer (0.90 g/cm<sup>3</sup>).
- High melting point (165–170 °C).
- End use temperatures of 100 °C.
- Good chemical resistance to hydrocarbons, alcohols, and non-oxidizing reagents.
- Good fatigue resistance (integral life hinge closures).
- Processed by all thermoplastic methods: injection molding, compression molding, blow molding, extrusion, cast films, and thermoforming (Campo, 2006).

### 2.5.2 Disadvantages and Limitations of Polypropylene

- Degraded by UV.
- Flammable, but flame retardant grades are available.
- Attacked by chlorinated solvents and aromatic solutions.
- Difficult to bond.
- Several metals accelerate oxidative degrading (Campo, 2006).

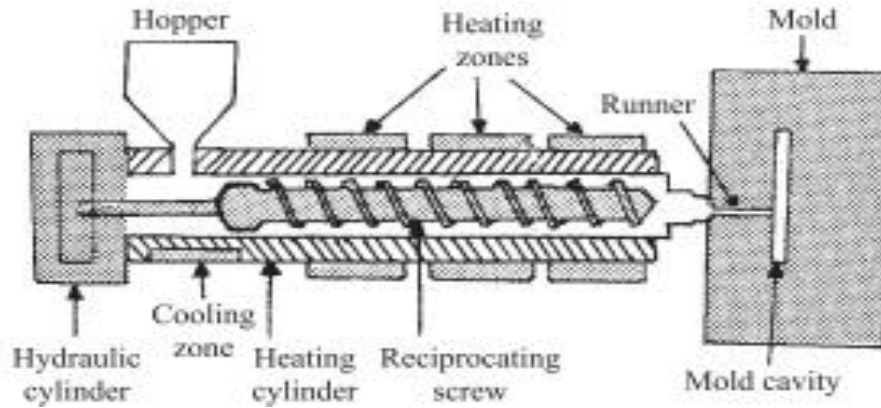
### 2.5.3 Typical Applications of polypropylene

- Flexible packaging films.
- Biaxial oriented packaging films.
- Stretched and oriented monofilament, tapes for textiles, carpeting, insulated medical fabrics and woven carpet backing

- Automotive interiors, bumpers, spoilers, air vent systems, under the hood components, internal wheel guards, and bellows
- Hygiene products, household goods and medical application trays, strainers, and containers
- Consumer products, such as closures, over caps, trigger sprayers, rigid and semi-rigid packaging, videocassette cases, toys, and electrical hardware
- Appliance housings and components, outdoor furniture, and luggage
- Injection blow molded stretch bottles with excellent stiffness, impact resistance, and clarity (Campo, 2006).

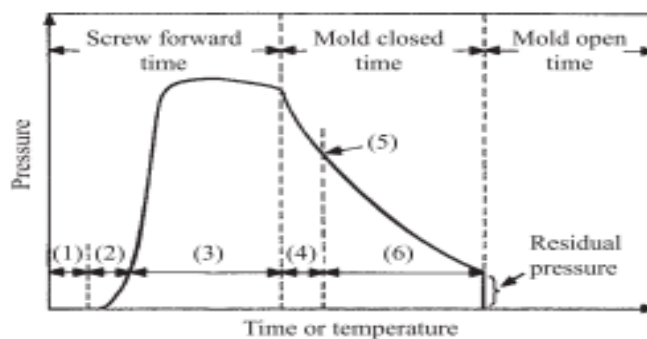
## **2.6 Injection molding Process**

Injection molding is one of the oldest polymer processing operations used to produce goods from thermoplastic polymers. Today, almost all commercial injection molding machines have a reciprocating single screw for softening (or melting) under heat a thermoplastic polymer, and polymer melt is then injected into an empty mold cavity. In the injection molding operation, the mold is first closed and then a predetermined amount of polymer melt from the screw section is injected into an empty mold cavity. Pressure is maintained for some time after the mold cavity has been filled to permit the build-up of adequate pressure in the mold cavity. Cooling water is circulated through channels in the mold to keep the mold cavity walls at a temperature usually between room temperature and the softening (or melting) temperature of the polymer. Thus, the hot polymer begins to cool as it enters the mold cavity. When it is cooled to a state of sufficient rigidity, the mold is opened and the part is removed. Some of the important variables in the operation of an injection-molding machine are: (1) pressure applied by the screw, (2) temperature profile of the screw section, (3) mold temperature, (4) the screw forward time, (5) the mold closed time, and (6) the mold open time. Relationships between these variables are very complicated. In general, one would like to know the pressure, temperature, and density of the polymer in the mold cavity as functions of time during and after the mold is filled.



**Figure 2.9 Typical screw-injection molding machine. (Han, 2007)**

Figure 2.9 representing the pressure–temperature (or time) relationships during the injection molding cycle, as shown in Figure 2.10. Referring to Figure 2.9, the following sequence of time periods is identified. (1) Dead time before the polymer starts flowing into the mold. (2) Filling time, during which the material is filling the cavity. (3) Packing time, during which the pressure increases rapidly and packing occurs (at this stage, melt flow into the cavity is at a very slow rate) accompanied by cooling. The compressibility of the polymer melt (or shrinkage during cooling or crystallization for semi crystalline polymers) allows some flow during pressure build-up. (4) Sealing time, during which cooling causes sealing at the gate of the cavity. (5) Sealed cooling time, during which further cooling causes the pressure remaining in the cavity to decay. (6) Ejection time, required for removing the molded part. (Han, 2007)



**Figure 2.10 Sequence of events during a typical injection molding cycle:**

**(1) dead time, (2) mold filling, (3) packing, (4) sealing, (5) sealed cooling, and (6) discharge. (Han, 2007)**

## **2.7 Process description**

The main units of a typical injection-molding machine are the clamping unit, the injection unit and the drive unit as shown in Figure 2.9.

The clamping unit holds the injection mold. It is capable of closing, clamping, and opening the mold. Its main components are the fixed and moving plates, the tie bars, and the mechanism for opening, closing and clamping. The injection unit melts the plastic and injected in to the mold. The drive unit provides power for the injection unit and the clamping unit.

### **2.7.1 Phase 1: melting preparation phase**

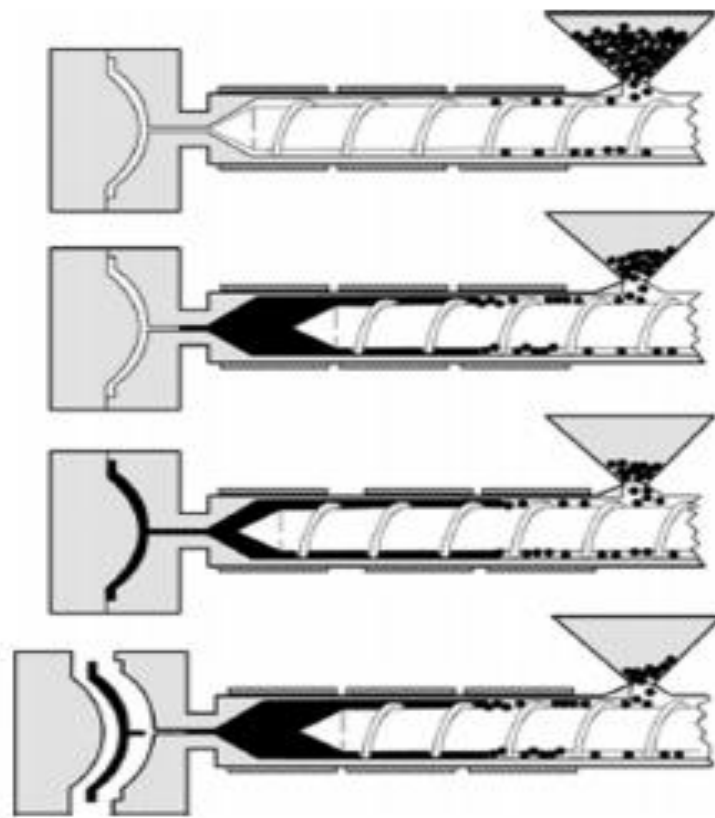
During the heating phase, plastic pellets are loaded in to the hopper. These pellets are gravity fed through of the throat of the hopper in to the barrel. in the barrel these pellets are heated by electrical band heaters and where applicable, friction arising from screw rotation. The electrical heater band inside the barrel as well as the shearing action of the rotating screw causes the material to melt. The most important temperature is the actual melt temperature, the temperature the material must be heated to before it is injected in to the cavity. All materials have a range of temperature at which they can be efficiently processed and still maintain their optimum mechanical properties (Benyounis, 2016).

### **2.7.2 Phase 2: injection phase**

The mold is closed and the nozzle of the extruder is pushed against the sprue bushing of the mold and the screw not rotating at this point. It pushed forward so that the plastic melt in front of the screw is forced in to the mold. Than the melt starts to fill the mold's cavities (Benyounis, 2016).

### **2.7.3 Phase 3: holding and solidification phase**

When the mold is completely filled, the screw remains stationary for some time to keep the pressure ;this is called the “ hold” time .during the hold time additional melt is injected in to the mold to compensate for contraction due to cooling and to avoid and shrinkage that may occur. When the gate freezes, the screw rotation is started. The period of screw rotation is called screw ‘recovery’. The rotation of the screw causes the plastic to be conveyed forward. As the plastic moves forward, heat from the electric heater bands along the barrel and shear starts to melt the plastic. At the discharge end of the screw, the plastic will be completely melted. The melt that accumulates at the end of the screw pushes the screw backward. Thus, the screw is rotating and moving backward at the same time. (Benyounis, 2016)



**Figure 2.11 Conventional injection molding process (Benyounis, 2016)**

Figure 2.11 shows the schematic of the injection molding process. This process has three main phases in injection molding cycle: melting preparation phase, injection phase and holding and solidification phase (Benyounis, 2016).

## **2.8 Design of Experiments**

Design of experiments is “A test or series of test in which purposeful changes are made to the input variable of a process or system so that we may observe and identify the reasons for changes that may be observed in the output response.” (C.Montgomery, 2001). In order to properly understanding a designed experiment, it is essential to have a good understanding of the process. A process is the transformation of input in to output. In the context of manufacturing, inputs are factors or process variables such as people, material, methods, environment, machine, procedures, etc. and output can be performance characteristic or quality characteristics of product. Sometimes, an output can also be referred to as response in performing a designed experiment; we will intentionally make changes to the input or machine variable (or factors). General model of Design of experiments process/system as shown in Figure 2.12

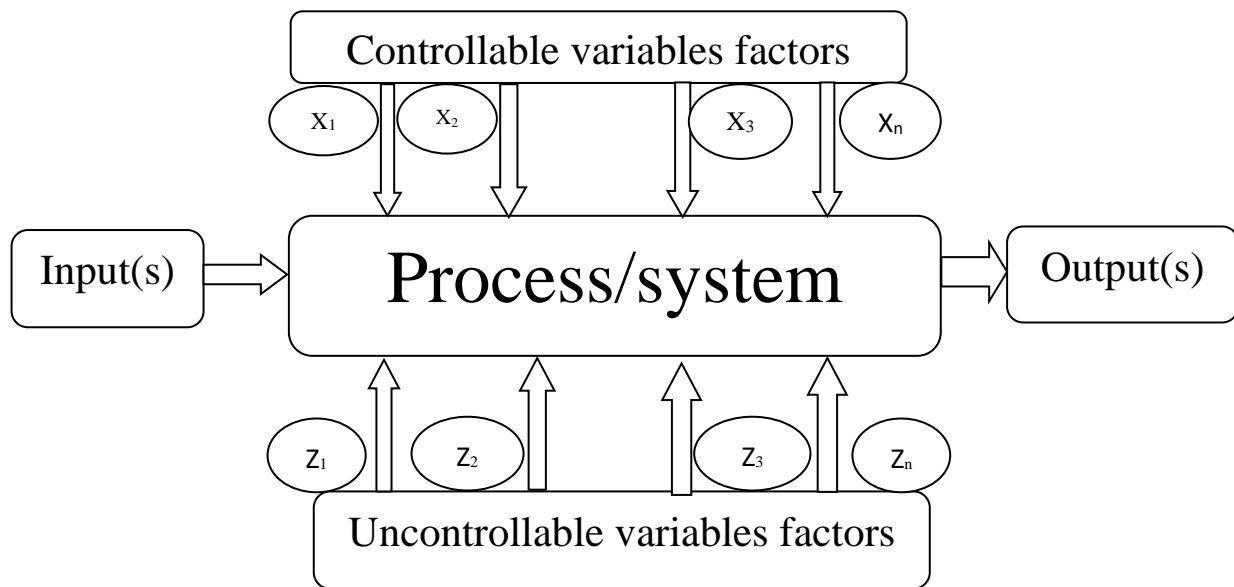


Figure 2.12 General model of a process/system (Antony, 2003)

## 2.9 Taguchi Methods

### 2.9.1 Taguchi philosophy

The goal of the Taguchi method is to find control factor settings that generate acceptable responses despite natural environmental and process variability. In each experiment, Taguchi's design approach employs two designs called the inner and outer array. The Taguchi experiment is the cross product of these two arrays. The control factors, used to tweak the process, form the inner array. The noise factors, associated with process or environmental variability, form the outer array. Taguchi's signal-to-noise ratios are functions of the observed responses over an outer array. The Taguchi designer supports all these features of the Taguchi method (Proust, 2012).

The foundation of the Taguchi methods is based on two premises:

1. Society incurs a loss any time the performance of a product is not on target. Taguchi has argued that any deviation from target performance results in a loss to society. He has redefined the term 'quality' to be the losses a product imparts to society from the time it is shipped.
2. Product and process design requires a systematic development, progressing stepwise through system design, parametric design, and finally, tolerance design. Taguchi methods provide an efficient, experimentation-based framework to achieve this.

The first premise suggests that whenever the performance of a product deviates from its target performance, society suffers a loss. Such a loss has two components: The manufacturer incurs a loss when his repairs or rectifies a returned or rejected product not measuring up to its target performance. The consumer incurs a loss in the form of inconvenience, monetary loss, or a hazardous consequence of using the product.

The second premise forms the foundation of quality engineering, a discipline that aims at engineering not only the function, but also quality performance into products and processes (Bagchi, 1993). To achieve desirable product quality by design, Dr. Taguchi recommends a three stage process.

3. Systems design
3. Parametric design
3. Tolerance design

**2.9.1.1 System design:** the focus of the system design phase is on determining the suitable working levels of design factors. It includes designing and testing a system based on the engineer's judgment of selected material, part, and nominal product process parameters based on current technology. Most often, it involves innovation and knowledge from the applicable fields of science and technology. While system design helps to identify the working levels of the design factors.

**2.9.1.2 Parametric design:** Seeks to determine the factors level that produce the best performance of the product /process under study. The optimum condition is selected so that the influence of the uncontrolled factors (noise factors) causes minimum variation of system performance.

**2.9.1.3 Tolerance design** is a step used to fine-tune the results of parameter design by tightening the tolerance of factors with significant influence on the product. Such steps will normally lead to identifying the need for better material, spending more money for better material, buying newer equipment, spending more money for inspection, etc. (Roy r. , 1990)

## **2.9.2 Achieving quality -Taguchi's seven points**

The following seven points highlight the distinguishing features of Taguchi's approach (as different from the traditional approach) which is aimed at assuring quality:

1. Taguchi defined the term 'quality' as the deviation from on-target performance, which appears at first to be a paradox. According to him, the quality of a

manufactured product is the total loss generated by that product to society from the time it is shipped.

2. In a competitive economy, Continuous Quality Improvement (CQI) and cost reduction are necessary for staying in business.
3. A CQI program includes continuous reduction in the variation of product performance characteristic in their target values.
4. Customer's loss attributable to product performance variation is often proportional to the square of the deviation of the performance characteristic from its target value.
5. The final quality and cost (R&D, manufacturing, and operating) of a manufactured product depend primarily on the engineering design of the product and its manufacturing process.
6. Variation in product (or process') performance can be reduced by exploiting the nonlinear effects of the product (or process) parameters on the performance characteristics.
7. Statistically planned experiments can efficiently and reliably identify the settings of product and process parameters that reduce performance variation (Bagchi, 1993).

### **2.9.3 Definition and measurement of quality**

Taguchi offers a general definition for quality of performance. He regards performance as the major component of product or process quality. A reduced variation result in a reduction in scrap, less rejection of product, and fewer warranty returns, consequently reducing cost and improving customer satisfaction.

Taguchi propose a mathematical formula called the loss function for estimating the monetary loss caused by lack of quality. The loss function estimates loss even if part are made with specification limit. That is necessary to allow for the fact that a company that makes all parts within specification limits still have warranty and customer complaints.

Taguchi defines loss as a quadratic expression in terms of measuring quality characteristic (y) of the part that ranges between the target value and the specification limits, that is, upper and lower specification limit. The loss function is defined such that when the part is made on the target, the loss is absent. The loss becomes the same as the cost of production of single parts, which is the cost of rejection, when all parts are made outside specification limits. The

loss between the target and the specification limits is of parabolic shape, symmetrical about the target (Roy R. , 2001). The relationship between quality loss and performance deviation from target as shown in Figure 2.13. Cost of poor quality, the actual cost of poor quality is higher than what can be calculated at the time of production. The Taguchi loss function can estimate the cost of quality at any performance level.

Loss within specification limit. It is possible to have a loss even if parts are made within specification limits. Loss is absent only when a part is made exactly on target. (Roy r. , 1990)

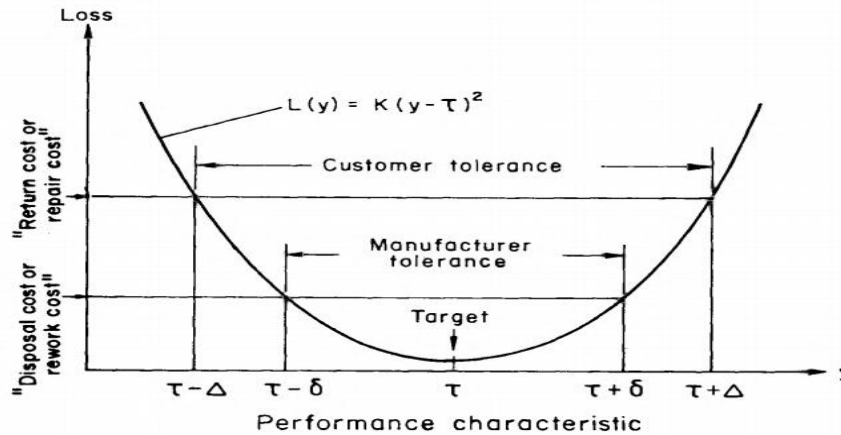


Figure 2.13 The relationship between quality loss and performance deviation from target. (Bagchi, 1993)

#### 2.9.4 Performance statistics and optimization using signal to noise ratio

The quadratic loss function  $L(y) = K(y - \tau)^2$  -----Equation 2.1

Appears more appropriate to maximize a performance aspect or minimize it; variations to the above loss function from are available. If the performance characteristic  $y$  happens to be such that the smaller it is the better, then one expresses the loss best by the expression,

$$L(Y) = ky^2 \text{-----Equation 2.2}$$

On the other hand if the performance characteristic is such that the larger it is the better, as with the bonding strength( $y$ ) of adhesives formulated, than

$$L(Y) = k\left(\frac{1}{y^2}\right) \text{-----Equation 2.3}$$

The S/N ratio is a concurrent statistic which is a special kind of data summary. A concurrent statistic is able to look at two characteristics of a distribution and roll these characteristics into a single number, or Figure of merit. The objective of robust design is specific: robust design seeks optimum settings of design parameters to achieve a particular target performance value under most noise conditions. Suppose that in a set of statistical experiments one finds the average quality characteristic to be  $\mu$ . and the

standard deviation (caused by the noise factors) to be a Let the desired performance be  $\sigma$ . Then one must make an adjustment in the design to get performance on target- by adjusting the value of a “control factor” by multiplying it by the factor  $(\mu^0/\mu)$ . However, this also affects the standard deviation. Since delivering on target performance is the goal, the loss after one has adjusted the process is now due to the variability remaining from the new standard deviation (of performance) only.

The factor  $\mu^2/\sigma^2$  reflects the ratio of average performance  $\mu^2$  (which is the signal), and  $\sigma^2$  (the variance in performance) the noise. Maximizing or the  $\mu^2/\sigma^2$  “S/N ratio” therefore becomes equivalent to minimizing the loss after adjustment. Additivity of design parameter effects is a primary requirement that permits use of the economical orthogonal statistical experiments in design optimization. For improving additivity one often takes the logarithm of  $\mu^2/\sigma^2$  and expresses the S/N ratio in decibels, as

$$S/N = 10 \log_{10} \mu^2/\sigma^2 \text{-----Equation 2.4}$$

Let  $Y_1, Y_2, \dots, Y_n$  represent multiple values of a performance characteristic  $Y$  observed in the parameter experiments. Then the following respective S/N ratios (denoted by  $S/N(\beta)$ ) become the most appropriate choices in guiding the Optimization of design parameter settings for the cases stated. If the nominal value for a characteristic  $Y$  is the best for the customer, then the designer should maximize the S/N ratio.

$$S/N(\beta) = 10 \log_{10} (\bar{y}^2/s^2) \text{-----Equation 2.5}$$

Where,

$$\bar{y} = \sum_{i=1}^n \frac{y_i}{n} \text{-----Equation 2.6}$$

$$s^2 = \sum_{i=1}^n \frac{(y_i - \bar{y})^2}{n-1} \text{-----Equation 2.7}$$

The idea that the “nominal” response is the best implies that if all observations  $\{y_i\}$  were exactly at the average (i.e., at  $\bar{y}$ ) and thus the variability in  $\{y_i\}$  was nil (i.e.,  $S^2$  was zero), the design would be the best. If being on target  $T$  is the best, then one should maximize.

$$S/N = 10 \log_{10} \tau^2/s^2 \text{-----Equation 2.8}$$

the S/N ratio is a predictor of quality loss that isolates the sensitivity of the product's function to noise factors. In robust design, one minimizes this sensitivity to noise by seeking combinations of the Design parameters settings that maximize the S/N ratio. Further, use of the S/N ratio attains robustness independent of target setting.

$$s^2 = \sum_i y_i - \tau^2 / n - 1 \text{-----Equation 2.9}$$

Than the above formula is reduced to

$$\text{Smaller is better S/N} = -10 \log_{10} \sum_i y_i^2 / n \text{-----Equation 2.10}$$

$$\text{Larger is better S/N} = -10 \log_{10} \sum_i 1/y_i^2 / n \text{-----Equation 2.11}$$

$$\text{Nominal is better S/N} = 10 \log_{10} y_{bar}^2 / s^2 \text{-----Equation 2.12}$$

(Bagchi, 1993).

## 2.10 Related research literatures

(Tranter et al, 2017) determine the effect of Melt Temperature, Mould Temperature, Holding pressure, Holding Time and Cooling Time on the energy consumption of injection molding process of acrylonitrile butadiene styrene (ABS), through direct energy measuring of equipment involved, and quality of the molded parts. The result showed that melt temperature=220°C, injection pressure =550bar, holding time 15sec, cooling time 40sec and mold temperature (35°C) was set at the high value.

(Maosheng et al, 2017) studied about Multi-objective optimization of injection molding process parameters in two stages for multiple quality characteristics and energy efficiency using Taguchi method and NSGA-II. The result showed that the melt temperature has an extremely important effect on both S/N ratio of product length deviation and warpage in Computer-aided engineering (CAE). And the optimal parameters for them are melt temperature =230°C, injection velocity = 90 mm/s, packing pressure = 65MPa, packing time = 4.5sec, and cooling time=5sec.

(Othman et al, 2017) investigated on Optimisation of Injection Moulding Parameter towards Shrinkage and Warpage for Polypropylene-Nanoclay-Gigantochloa Scortechinii Nano composites According to his results, the value of warpage was reduced when the fiber content was increased from 1 wt. % to 3 wt. %. The warpage value changed from 0.025mm to 0.009mm. The optimum parameter for warpage were 175°C barrel temperature, 40% packing pressure, 35% screw speed and 2 seconds filling time for both 1 wt. % and 3% of

GS fiber. However, in terms of shrinkage, the increment of fiber content doesn't have much impact towards the response. The value of shrinkage was reduced but not significantly from 0.0136mm to 0.0134mm when the percentage of fiber was added. The optimum parameter for 1 wt. % fiber to control shrinkage are 170°C melt temperature, 35% packing pressure, 30% screw speed and 2 seconds of filling time.

(Lopez et al, 2016) studied on injection moulding parameters influence on weight quality of complex parts by means of DOE application. This paper agree that the injection parameters influence on the weight of a weight quality of product.

(B.Kc et al, 2016) focused on optimization of injection molding parameters using Taguchi method for reducing shrinkage. his analys on optimization showed that the methd was successful for reducing shirinkage. And he was suggested that optimal injection molding settings for minimizing flow shrinkage are injection pressure 90bar, melt temperature 210°C, mold temperature 40°C, cooling time 40sec and hold time 6sec while optimal holding pressure was 70 bar for SF20GF10 and 50 bar for SF10GF20. Based on ANOVA analysis, injection pressure had a significant influence on both flow shrinkage and x-flow shrinkage of SF20GF10. For SF10GF20, no factors showed significant impact on flow shrinkage; however injection pressure and mold temperature had a significant impact on x-flow shrinkage. Other factors did not have a significant impact on shrinkage.

(Mei-Ling et al, 2016) studied on validation of Taguchi, response surface, neural network, and genetic algorithm methods on the quality improvement of piston manufacturing processes. with five control factors consisting of type of carbon steel, type of cutting fluid, cutting depth, spindle speed, and chuck pressure, the L27(3<sup>13</sup>) orthogonal array was selected for his experiments. Taguchi method has the best experimental efficiency, the differences to the specification targets of the experimental results ranks.

(Xie et al, 2015) give intantion on effects of process parameters on quality of ultrafine WC/12Co cemented carbide powde injection molded compacts. The resercher selected five control factors with three level these are Melt temperature, Injection pressure, Injection speed, Packing pressure and Mold temperature. From his analysis of flexural strength data, the optimal combination of process parameters was melt temperature of 155 °C, injection pressure of 120 MPa, injection speed of 80%, packing pressure of 30 MPa and mold temperature 35 °C.

(Xinyu et al, 2015) examined that warpage optimization with dynamic injection molding technology and sequential optimization method. The result shows that warpage is reduced and his optimization result suggests an argument that DIMIT can improve the quality of the plastic part than the conventional.

(Kurniawan et al, 2014) investigated on two stage optimization system to find optimal process parameters of multiple quality characteristics in plastic injection molding. Taguchi method, Back-Propagation Neural Network (BPNN), Genetic Algorithm (GA), and combination of Particle Swarm Optimization and Genetic Algorithm (PSO-GA) are used in this study to find optimum parameter settings. Melt temperature, injection velocity, packing pressure, packing time, and cooling time are selected as initial process parameters in the experiment. The result showed that the optimal setting of plastic injection molding was Melt temperature (°C) 255 Injection velocity (mm/s) 38 Packing pressure (MPa) 33 Packing time (s) 1.95 Cooling time (s) 20.

(Fu Gu et al, 2014) study about improvement of mechanical properties of recycled recycled polypropylene (PP) plastic blends via optimizing processing parameters using the Taguchi method and principal component analysis. The researcher select melt temperature, mold temperature, injection speed and packing pressure as controllable factors in three levels. He showed that the processing parameters for injection molding have a significant impact on the performance of products. Especially on their mechanical properties.

(Kemal et al, 2014) investigated in improvement of changeover times via Taguchi empowered SMED/case study on injection molding production. The paper used Taguchi design of Experiment method with four factors and three levels. This paper pointed to the optimum setting of plastic injection molding machine is Melt temperature=230, Packing Pressure=100, Cooling time=30, Injection pressure=80.

(Wang et al, 2014) investigated on optimization of plastic injection molding process parameters for manufacturing a brake booster valve body. This paper used the following parameters considered for optimization: number of gates, gate size, molding temperature, resin temperature, switch over by volume filled, switch over by injection pressure, and curing time. An orthogonal array of L18 is created for the statistical design of experiments based on the Taguchi method. This showed that the optimal plastic injection molding machine process parameters are Number of gates 4, Gate size 22.86, Molding temperature 180.4,

Resin temperature 85.5, Switch over by volume filled 69.57, Switch over by injection pressure 13.2, Curing time 132.

(Öktem, 2012) focused on Optimum process conditions on shrinkage of an injected-molded part of DVD-ROM cover using Taguchi robust method the result showed that ANOVA grades exposed that the injection time (48.93%) and the melt temperature (45.44%) are statistically the most significant process conditions on shrinkage, whereas the melt temperature (50.6%), injection time (41.82%), and mold temperature (2.61%) are the most significant process conditions on shrinkage (at ejection). The S/N ratio results in to consideration, it can be showed that the optimum process conditions for shrinkage correspond to a mold temperature of 40°C, a melt temperature of 230°C, an injection pressure of 100 MPa, an injection time of 3 s, and a cooling time of 20 s, while the optimum process conditions for shrinkage (at ejection) are a mold temperature of 60°C, a melt temperature of 230°C, an injection pressure of 100 MPa, an injection time of 3 s, and a cooling time of 20 s.

(Yin Fei et al, 2011) give attention to a hybrid of back propagation and genetic algorithm optimization method of injection molding process parameters is presented systematically on the basis of finite element analysis software Moldflow, Orthogonal experiment method, back propagation neural network and genetic algorithm. The paper optimized Warpage and clamp force in plastic injection molding machine. The paper used Mold temperature, melt temperature, packing pressure, packing time as well as the cooling time are considered to be design variables. The writer recommended process parameters used by moldflow softwer these are Mold temperature=60, melt temperature=240,packing pressure=100, packing time=8 as well as the cooling time=15.

(Ozcelik et al, 2010) studeid about optimized effect of injection parameters such as melt temperature, packing pressure, cooling time and injection pressure on the mechanical properties of Acrylonitrile–Butadiene–Styrene (ABS) moldings. the change of mechanical properties of ABS material was optimized by ANOVA and regression analysis with respect to injection parameters and two mold materials. he was importantly suggested that The most important parameter affecting the elasticity module, tensile strength and tensile strain at yield, tensile strain at break was melt temperature and its effect was determined for steel as 84.90%, 86.78%, 50.05% and 42.99%, respectively. The other parameter affected by flexural module(73.26%) was injection pressure.

(Amel Kamoun et al, 2009) Dedicated on the use of the simplex method and its derivatives to the on-line optimization of the parameters of an injection molding process. The investigators used variable size simplex in order to minimize the cycle time and secondarily reduce the percentage of rejects for an injection molding process. The results clearly showed that the process cycle time was very sensitive to the effect of two parameters: cooling time and holding pressure. Low levels of these two parameters were necessary in order to minimize the cycle time. The percentage of rejects was also very sensitive to the cooling time and holding pressure levels; it was much lower when the levels of these two parameters were low. These results allow us to conclude that variable size simplex were a suitable method for on-line optimization in situations where processes have time-varying operating conditions or trends to drift. It easily used and re used on-line to drive the process continuously towards its optimal conditions.

(Chen et al, 2009) deals about the application computer-aided engineering integrating with statistical technique to reduce warpage variation depended on injection molding process parameters during production of thin-shell plastic components. The researcher selected the following parameters for his investigation, these are Melt temperature, Mold temperature, Inject speed, Packing pressure. he compare and contrast about the simulational and expermental data, optimal parameter combination of the simulation process corresponded to a melting temperature of 329.96°C, a mold temperature of 129.65°C, a injection speed of 75.19%, and a parking pressure of 49.99 MPa. The optimal parameter combination of the experiment is conducted with a melting temperature of 330.00°C, a mold temperature of 121.17°C, an injection speed of 81.48%, and a parking pressure of 50.00 MPa. The optimal parameter combination via both simulation and experiment process can be shown the melting temperature and parking pressure is similar parameter. And also The ANOVA result indicates that the melt temperature and the packing pressure are found to be the most significant controlled parameters in both the simulation and the experimental analysis.

(Tuncay and Babur , 2006) investigated on minimization of warpage and sink index in injection-molded thermoplastic parts using Taguchi optimization method. The investigators used the following parameters to minimize warpage and sink index; Mold temperature (°C), Melt temperature (°C), Packing pressure (MPa), Rib cross-section types and Rib layout angle. The results showed that for the minimizations of the warpage and sink index in terms of process parameters of the plastic parts have different rib cross-section types, and rib layout

angle using Taguchi optimization method are below: Triangle rib cross-section type and rectangle rib cross-section type are located with 45° and 90° angle according to X direction was obtained as the most suitable rib for minimum warpage and sink index of PC/ABS and PA66 polymer materials, respectively. Trapezoidal rib cross-section types are located with 45° and 90° angle according to X direction was obtained as the most suitable rib for minimum warpage and sink index of POM polymer material.

### **2.11 Motivation**

Motivation behind this research work is the growth of plastic industry as well as the growth of demands of high quality with low cost plastic products. Now a day society needs high quality plastic products which are used for house hold and office equipments. However, the exact product that is needed by the society is not delivering due to low quality. The problems associated with quality are caused by improper selection process parameters of plastic injection molding machine. Hence, this research work is conducted to optimize process parameters of plastic injection molding process to reduce flash and short shot defects. No research work was investigated on the optimization of process parameter of injection molding process to reduce flash and short shot defects, from the reviewed literatures. This thesis work will fill the research gap and solve the problems observed in Ameze plastic factory.

## **CHAPTER THREE**

### **Materials and Methods**

#### **3.1 Introduction**

The main objectives of this chapter is to further explore about the necessary material and methods to optimize the process parameters of plastic injection molding Machin. This chapter contains plastic material, injection molding machine, experimental measuring instrument, experimental method and experimental design.

#### **3.2 Plastic Material**

The experiment has been carried out on polypropylene material used to produce laundry bucket of length 70cm, top diameter 55cm and bottom diameter 30cm and vegetable crates length 50, width 30 and high 35. Plastic material used to manufacture laundry bucket and vegetable crates was polypropylene grade of P640J manufactured by Thail Polyethylene co as shown in Figure 3.1. Let. Polypropylene P640J is an impact copolymer polypropylene that is suitable for injection molding process. Polypropylene have a characteristic of High impact strength, high stiffness and good process ability. Recommended injection molding process parameter setting for polypropylene are shown in Table 3.1.



**Figure 3.1 Polypropylene material p640J**

**Table 3.1 Material characteristic of polypropylene material**

Property	Test method	Value	Unit
Melt flow rate	ASMT D @ 230 <sup>0</sup> C, 2.16 kg	10	g/min
Density	ASMT D 1505	0.910	g/cm
Tensile strength at yield	ASMT D 638 @ crosshead speed 50 mm/min	280	kg/cm <sup>2</sup>
Tensile strength at break	ASMT D 638 @ crosshead speed 50 mm/min	200	kg/cm <sup>2</sup>
Elongation at break	ASMT D638 @ crosshead speed 50 mm/min	300	%
Flexural modulus	ASMT D 790	12000	kg/cm <sup>2</sup>
Notched Izod impact	ASMT D 256 @23 <sup>0</sup> C	10	kg.cm/cm
Notched Izod impact	ASMT D 256 @0 <sup>0</sup> C	5	kg.cm/cm
Notched Izod impact	ASMT D 256 @-20 <sup>0</sup> C	4	kg.cm/cm
Rockwell hardness	ASMT D 785	70	R-scale
Haze	ASMT D 1003	80	%
Gloss	ASMT D 2457	30	%
Melting point	ASMT D 2117	163,120	<sup>0</sup> C
Vicat softening	ASMT D1525	150	<sup>0</sup> C
Heat deflection temperature (HDT)	ASMT D 648 @ 4.6 kg/cm <sup>2</sup>	105	<sup>0</sup> C
Heat deflection temperature (HDT)	ASMT D 648 @ 18.5 kg/cm <sup>2</sup>	55	<sup>0</sup> C
Brittleness temperature	ASMT D 746	-20	<sup>0</sup> C
% shrinkage (2mm)			
MD	TPE method	1.25	%
TD	TPE method	1.09	%
Flammability	UL-94	HB	-
Note :conversion factor for changing unit from kg/cm <sup>2</sup> to MPa is divided by 10.20			

### 3.3 Injection molding machine

This paper work was used TIANJIAN Plastic injection molding machine of PL 7800 to manufacture laundry bucket and PL 10,000 are used to manufacture vegetable crates. The specification of TIANJIAN machine PL 7800 and PL 10,000 are shown in Table 3.2 and 3.3 and the illustration of plastic injection molding machine as shown in Figure 3.2 and 3.3.

**Table 3.2 TIANJIAN plastic injection molding machine specification 7800**

Item	Unit	Maximum capacity
Screw diameter	Mm	110
Injection volume	cm <sup>3</sup>	3849
Injection capacity	G	3502
Injection speed rate	g/s	790
Injection pressure	MPa	223
Injection stroke	Mm	405
Heating input power	kW	49.25
Clamping force	kN	7500



**Figure 3.2 TIANJIAN plastic injection molding machine PL 7800**

**Table 3.3 TIANJIAN plastic injection molding machine specification P 10,000**

Item	Unit	Maximum capacity
Screw diameter	Mm	200
Injection volume	cm <sup>3</sup>	5849
Injection capacity	G	5502
Injection speed rate	g/s	1200
Injection pressure	MPa	280
Injection stroke	Mm	495
Heating input power	kW	65.40
Clamping force	kN	10000



**Figure 3.3 TIANJIAN plastic injection molding machine PL 10,000**

### **3.4 Experimental Measuring Instrument**

The product of plastic bucket weight is measured using F1976 digital weight measurement as shown in Figure 3.4. F1976 digital weight measurement has measuring a range up to 200g-40 kg and precision up to 0.005 kg. The test was performed on at a room temperature after 24 hours of its production.



**Figure 3.4 F1976 digital weight measurement**

### **3.5 Experimental method**

The investigation process in plastic injection molding machine have the following procedure; select defects on plastic injection molding machine, investigate failure mode analysis of plastic injection molding machine product, investigate on the cause of defect and select the critical defects in Ameze plastic factory, select variable and its level, conducting the experiment, run the experiment by using Taguchi method.

The following three illustrated steps were followed for this research work to optimize plastic injection molding machine and the flowchart of methodology illustrated in Figure 3.5

Stage 1:

- In this stage, investigate the failure mode analysis of product in plastic injection molding machine.
- Based on the failure mode analysis select critical defects in Ameze plastic factory.
- Based on machine manual, literature review, polypropylene P640J property, brainstorming and discussion with machine experts selected the control factors and its levels.
- From the control factors and level the orthogonal array was decide.

Stage 2:

- Conducted the experiments based on the orthogonal array value
- Analyze the result of the experiment based on S/N ratio. This stage, determined the optimum parameter setting and effect of process parameters.

Stage 3:

- Identified the significant factors of process parameters using ANOVA value
- Conform the experiment by compared the percentage of defects before conducting the experiment and ran the machine by set optimal setting.
- The percentage defects shows maximize or no change start the experiment by changing the control factor and its level. However, it shows reducing valid the experiment and finished the work.

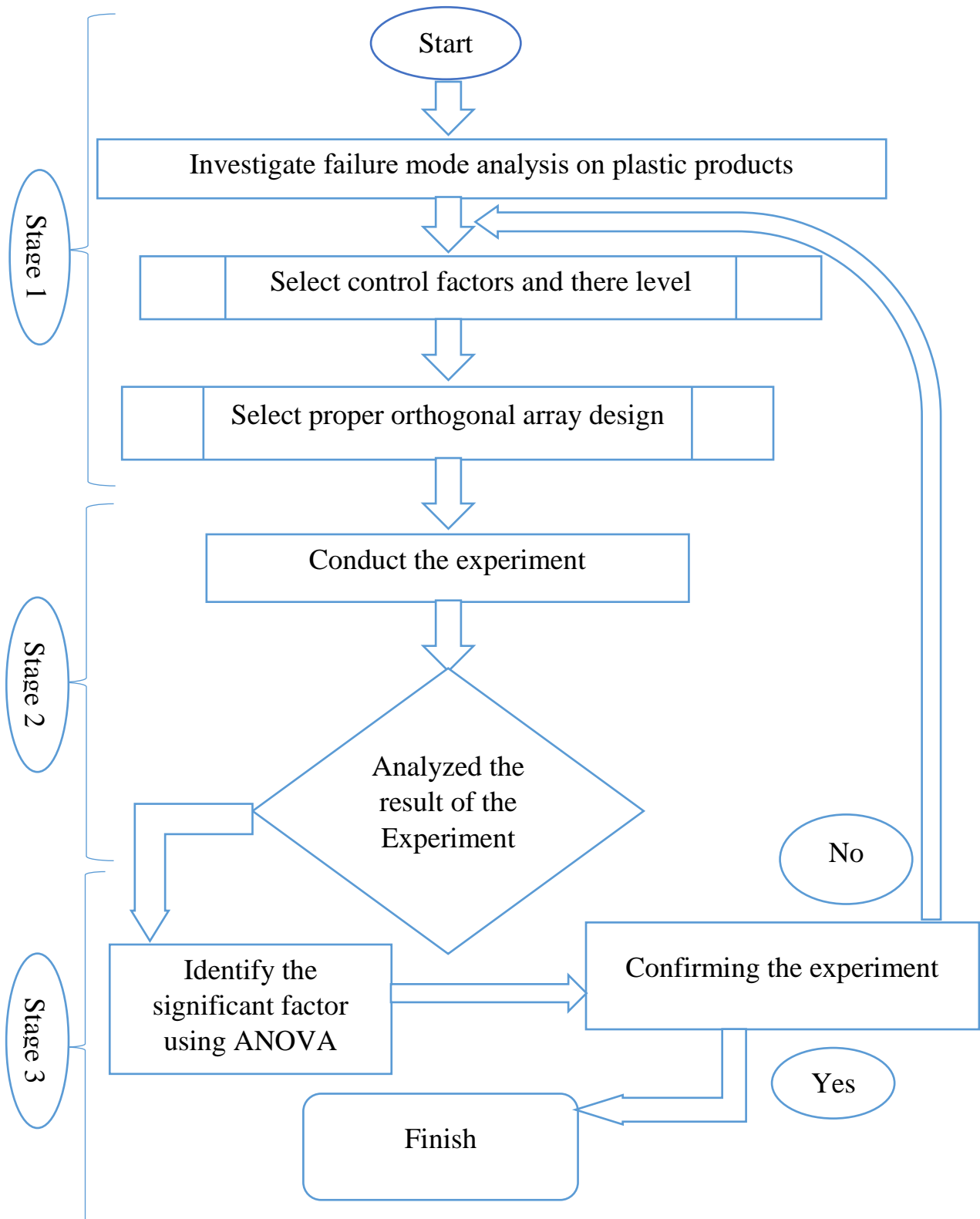


Figure 3.5 Flowchart of methodology

### **3.6 Experimental Design**

Experimental design should be performed before the experimental work is conducted. This stage is very important to get reliable data. Generally, there are three experimental techniques in conducting experiment: factorial design, the Taguchi method, and random design. If we have a small number of variables or factors with a few levels, then factorial design is an appropriate technique to be used. Experimental work using factorial design is used to test all possibilities of all combinations. This technique is very good to be used when the interaction between variables are assumed strong and very important. However, when the control factors and level become higher, then huge number of experiments should be conducted, orthogonal array from the Taguchi method provide efficiency in the experiment. Similar information as performed in factorial design with fewer experiments can be done using the Taguchi method. Instead of performing all possible combinations of control factors, the Taguchi method has ability to assess all pairs of combinations in some more efficient way. In random design, experimental conditions with high probability create a near optimal design. However, this design tends to work poorly for small number of experiments, but works well for large systems.

In this research work Taguchi method was used to optimize plastic injection molding machine process parameters to determine the best combination of process parameter with a minimum number of experiments, it leads to minimized experimental time, cost of product and cost of material which experiments are run. Taguchi method specifies the best combination of process parameters and effect of process parameter in the output result using signal to noise ratio(S/N). By using the Taguchi method in Minitab17, the suitable Orthogonal Array was L27 with five factors and three levels. Taguchi recommends L 27 Orthogonal Array for 5-13 factors. Orthogonal Array of L 27 are illustrated in Table 3.4 the S/N ratio of “smaller the better” selected since the experiment was to minimize flash and short shot defect on plastic injection molding machine. It is compatible to use equation 2.10.

Smaller is better  $S/N = -10 \log_{10} \sum_i y_i^2 / n$

The controllable factors were selected based on literature review brainstorming and discussion with machine experts. These parameters are Melt temperature, Holding Pressure, Injection Pressure, Injection speed, cooling time. It was used to identify the suitable parameter setting of plastic injection molding machine. A static analysis of variance (ANOVA) was used to identify the significant factors of the process parameters.

**Table 3.4 Orthogonal array L 27**

<b>M.T(°C)</b>	<b>H.P (MPa)</b>	<b>I.P (MPa)</b>	<b>I.S (rpm)</b>	<b>C.T (Sec)</b>
230	42	56	40	45
230	42	56	40	55
230	42	56	40	65
230	63	84	55	45
230	63	84	55	55
230	63	84	55	65
230	84	112	70	45
230	84	112	70	55
230	84	112	70	65
250	42	84	70	45
250	42	84	70	55
250	42	84	70	65
250	63	112	40	45
250	63	112	40	55
250	63	112	40	65
250	84	56	55	45
250	84	56	55	55
250	84	56	55	65
270	42	112	55	45
270	42	112	55	55
270	42	112	55	65
270	63	56	70	45
270	63	56	70	55
270	63	56	70	65
270	84	84	40	45
270	84	84	40	55
270	84	84	40	65

## **CHAPTER FOUR**

### **4. Results and Discussion**

#### **4.1 Introduction**

This chapter is composed according to the material and method from the previous chapter. The purpose of this chapter is to present the detail experimental works of the research. The measurements from the tests will be analyzed and evaluation by using Taguchi method of orthogonal array by using signal to noise ratio and ANOVA. This chapter including failure mode analysis of plastic injection molding machine products, the cause and effect of plastic product defects, Taguchi orthogonal array result and discussion, analysis of variance, confirmation experimental work.

#### **4.2 Failure mode analysis**

The aim of the analysis of Taguchi orthogonal array is to evaluate the best combination of process parameters of plastic injection molding machine reduce potential defects of plastic injection molding machine product in Ameze plastic factory. The potential defects of plastic injection molding machine are selected based on failure mode analysis in sigma XL. Failure Mode Effect Analysis (FMEA) Provide a Basic familiarization with a tool that aids in quantifying severity, occurrences and detection of failures, and guides the creation of corrective action, process improvement and risk mitigation plans.

(Issa Bass, 2009) described failure modes and effects analysis (FMEA) as “A graphical presentation of an FMEA is generally a representation of two combined matrices: on one side is the failure mode and effect part, which consists of developing a list of all the causes of the potential failures and their effects on the overall process or product, and on the other side is the action plan, which determines what needs to be done to prevent the failures from materializing. FMEA have the following components;

1. Potential failure mode-Potential failure mode describes the way in which the corresponding item listed in the process step or product function could possibly fail to satisfy its intended purpose.
2. Potential effect of the failure-Potential effect of the failure describes the impact of the failure on the functionality of the product or process (Issa Bass, 2009).
3. Potential causes of the failure-This describes the flaws of the design that may lead to a potential failure

4. Severity-The severity measures how critical or serious a potential failure can be on the product or process. If the failure is so serious that it can stop production, it is graded 10 and if it is very easy to correct, it is graded 1.
5. Detection-Detection is a measure of the ability to detect preemptively the failures. If the potential failure is easy to detect, the grade should be low (1 for very easy to detect and 10 for very hard).
6. Occurrence-The occurrence measures how often the failure is likely to happen. The likelihood of an occurrence is expressed in ranking from 1 to 10 (1 for rare and 10 for often).
7. Current control-Current controls are known preventive controls that are currently being used in similar processes or products.
8. Risk priority number-The risk priority number (RPN) helps to rank the failures and establish their precedence for problem resolution considerations. The RPN is the product of the severity, detection, and occurrence levels. The higher the RPN, the more attention that particular step of the process or that characteristic of the product should get.
9. Recommended actions-The recommended preventive actions are generally suggested by the FMEA team during a brainstorming session (Issa Bass, 2009).

**Table 4.1 Failure Mode Effect Analysis (FMEA) of plastic injection molding machine**

<div style="background-color: #cccccc; padding: 5px; text-align: center;">Row Number</div> <div style="border: 1px solid black; padding: 2px; text-align: center; width: 40px; margin: 2px auto;">Sort</div>	Defects	Potential Failure Mode	Potential Effects of Failure	Severity (1-10)	Potential Cause(s) of Failure	Occurrence (1-10)	Current Controls	Detection (1-10)	<div style="background-color: #cccccc; padding: 5px; text-align: center;">Risk Priority Number (RPN)</div> <div style="border: 1px solid black; padding: 2px; text-align: center; width: 40px; margin: 2px auto;">Sort</div>	Recommended Action
1	Flow Lines	Streaks, Patterns, or Lines created	Loss of attractiveness of product	2	Varying speed at which the molten plastic flows as it changes direction	3	no action taken	7	42	Find the optimum setting of the process parameters and also Increase injection speeds and pressure to the optimal level
2	Flash	Molten plastic escapes from the mold cavity	Scrap, incompatible product Material loss and Labor cost	8	The mold is not clamped together with enough force	10	Remove the scrap	7	560	Adopt optimal molding conditions like injection speed, injection pressure, mold temperature, melting temperature and etc...

3	Sink Marks	Small craters or depressions are created	Loss of attractiveness of product rejection and Rework	4	In adequate pressure in the cavity, or an excessive temperature at the gate	2	tried to sell the products with minimum cost	9	72	Mold temperatures should be lowered, holding pressure increased, and holding time prolonged to allow for more adequate cooling and curing
4	Vacuum Voids	Pockets of air trapped are created	Loss of attractiveness of product and Rework	4	Uneven solidification between the surface and the inner sections of prototype	2	no action taken	9	72	Increase holding pressure as well as holding time.
5	Short Shots	The mold cavity is not fully occupy	rejection and Rework	7	Incorrect calibration of the shot, plastic is too viscous and it may solidify before fully occupying all the cavities	8	Rework the process by changing the parameters	7	392	Optimize the process parameters of plastic injection molding.

6	Surface Delamination	Thin surface layers appear	Loss of attractiveness of product	4	Foreign materials contamination	3	tried to sell the products with minimum cost	10	120	Find the optimum setting of the process parameters
7	Weld Lines	Plane appears in the meeting part of the mold	Scrap and Labor cost	1	Weld lines are caused by the inadequate bonding of two or more flow fronts when there is partial solidification of the molten plastic	4	no action taken	7	28	Adjust the design for the flow pattern to be a single source flow.
8	Warping	Twisted, uneven, or bent shape occur	Rework and rejection	2	Non-uniform cooling of the mold material. Different cooling rates in different parts of the mold cause the plastic to cool differently and thus create internal stresses	3	Rework the process by changing the parameters	10	60	Optimize the process parameters of plastic injection molding.

9	Burn Marks	Rust colored	Loss of attractiveness of product	1	Degradation of the plastic material due to excessive heating or by injection speeds that are too fast	4	tried to sell the products with minimum cost	5	20	Reduce injection speeds mold and melt temperatures, Optimize gas venting
10	Jetting	Molten plastic fails to stick to the mold surface	Rework, Machin cost and Labor cost	2	the melt temperature is too low and the viscosity of the molten plastic becomes too high, thereby increasing the resistance of its flow through the mold	3	tried to sell the products with minimum cost	8	48	Optimize gate design to ensure adequate contact between the molten plastic and the mold

From the Failure mode analysis as shown in table 4.1 is allowed to study and analyze plastic injection molding machine defects in Ameze plastic factory. The current action taken to control the plastic product wastes, the company tried to sell the product with minimum cost. This process achieve and improve product quality of plastic product by applying recommended action. From the failure mode analysis flash and short shot have high risk priority number i.e. for flash 560 and for short shot 392. Therefore, recommended action are taken in both defects. The recommended Action to reduce both defect are to find the optimum process parameters setting of plastic injection molding machine. The improvements obtained by the implementation of the recommended actions thus reduce the individual RPN and the risk level associated with each defect.

### 4.3 Cause and Effect

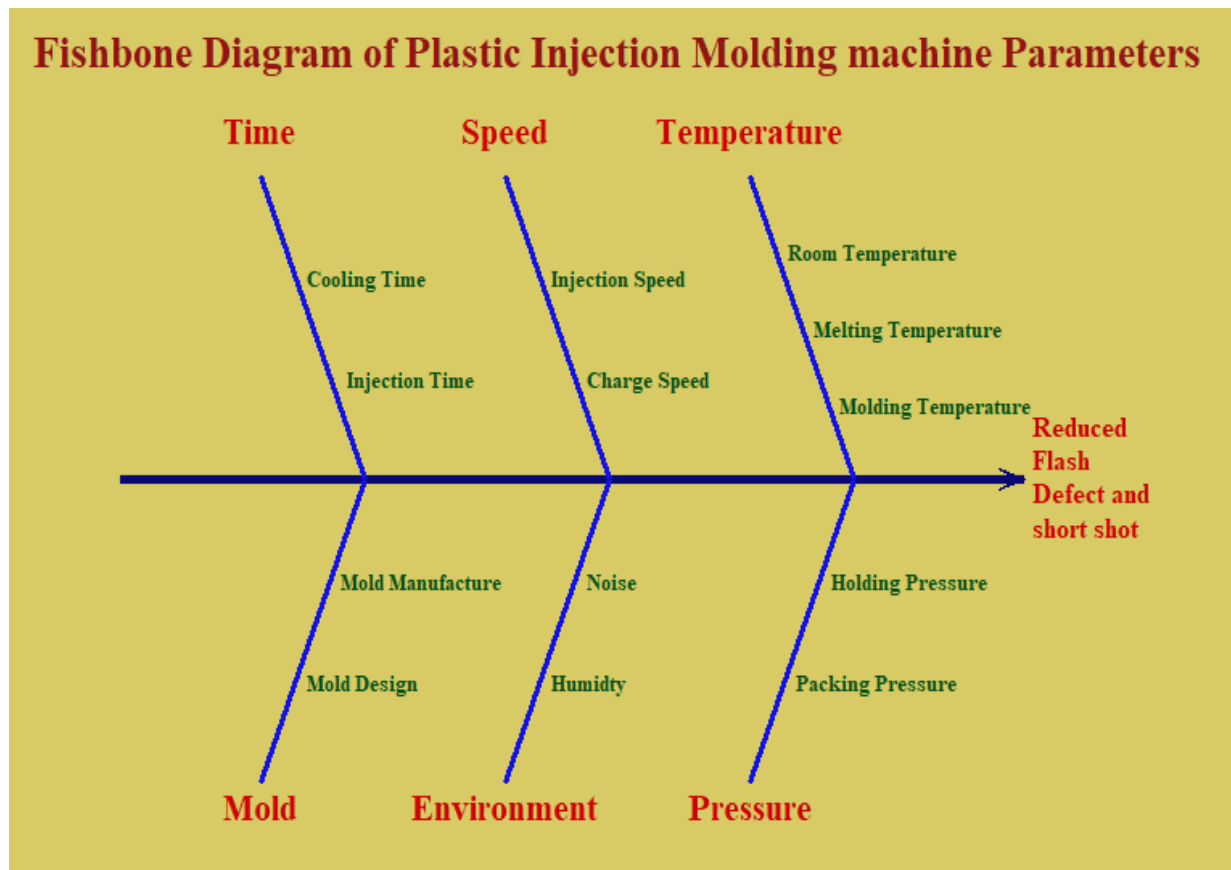
Flash and short shot defects are common in plastic injection molding machine, it is extremely difficult to reduce this type of defects. In addition, it reduced the quality of product as shown in figure 4.1 flash defect and in figure 4.2 short shot defect. It is necessary to investigate on parameters of injection molding machine which are reason for flash defect and short shot on injection molding machine. Many process parameters have direct impact on the quality and cost of product. However, the main cause of flash and short shot defect in plastic injection molding machine are time, speed, Temperature, mold, Environment, pressure. The detail are shown in fishbone diagram in Figure 4.3



**Figure 4.1 Flash defect on laundry bucket.**



**Figure 4.2 Short shot on laundry bucket.**



**Figure 4.3 Fishbone diagram of plastic injection molding machine parameters**

The objective of this paper work is minimizing flash and short shot defect on plastic injection molding machine. The main cause of flash and short shot defect are process parameters. As a result, Process parameters of plastic injection molding machine in this paper work are select based on machine manual, literature review, polypropylene p640J property, brainstorming and discussion with machine experts. Selected factors are shown in Table 4.2. The illustration of their factors and there levels are shown in Table 4.3.

**Table 4.2 Injection molding process parameter for polypropylene**

Factors	Levels
Melting temperature	230°C-270°C
Holding pressure	42 MPa – 84 MPa
Injection pressure	56 MPa - 112 MPa
Injection speed	40 rpm-70 rpm
Cooling time	45 sec-65 sec

**Table 4.3 Injection molding machine parameters and their levels**

Factors	Level 1	Level 2	Level 3
Melting Temperature	230	250	270
Holding Pressure	42	63	84
Injection Pressure	56	84	112
Injection Speed	40	55	70
Cooling Time	45	55	65

#### 4.4 Taguchi orthogonal array result

Based on the design of orthogonal array, three trials are performed for each combination of orthogonal arrays parametric setting. The control factor and its experimental result of each treatments are recorded in Table below 4.4 for flash defect and table 4.7 for short shot defect.

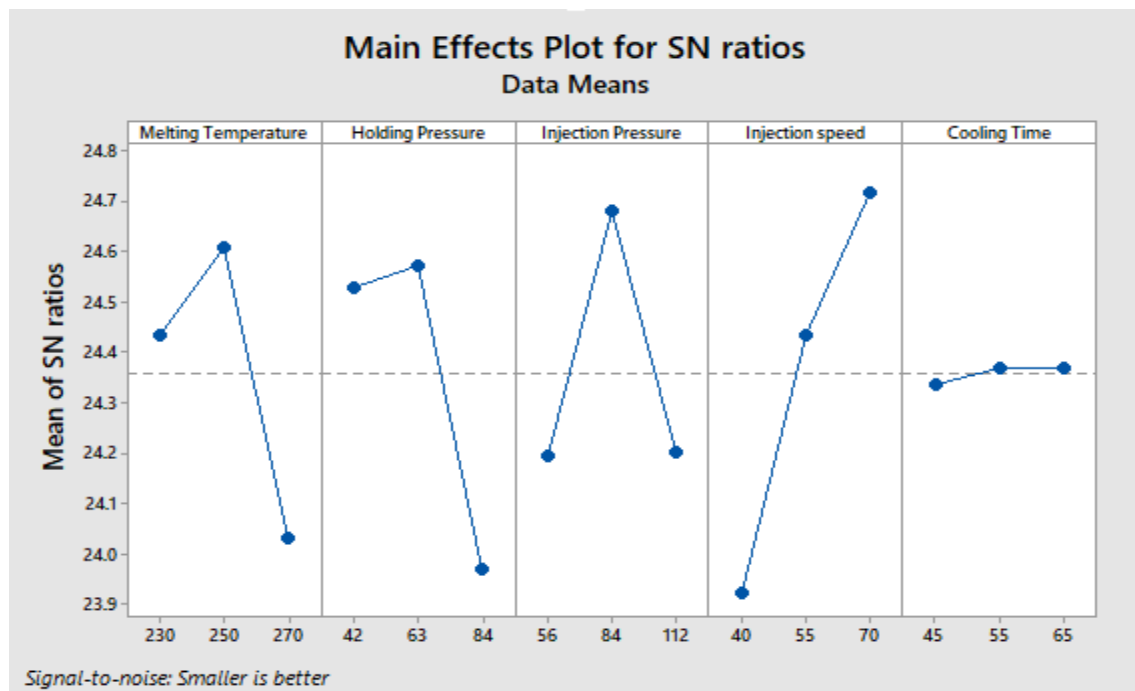
**Table 4.4 Taguchi orthogonal array result for flash defect**

Run	M.T	H.P	I.P	I.S	C.T	Result 1	Result 2	Result 3	S/N ratio
1	230	42	56	40	45	0.045	0.045	0.055	26.2739
2	230	42	56	40	55	0.065	0.065	0.055	24.1737
3	230	42	56	40	65	0.085	0.080	0.085	21.5802
4	230	63	84	55	45	0.075	0.065	0.060	23.4840
5	230	63	84	55	55	0.045	0.045	0.060	25.9346
6	230	63	84	55	65	0.050	0.055	0.050	25.7268
7	230	84	112	70	45	0.065	0.065	0.065	23.7417
8	230	84	112	70	55	0.085	0.080	0.080	21.7555
9	230	84	112	70	65	0.040	0.045	0.045	27.2507
10	250	42	84	70	45	0.035	0.055	0.050	26.4782
11	250	42	84	70	55	0.050	0.045	0.045	26.6088
12	250	42	84	70	65	0.075	0.065	0.065	23.2867
13	250	63	112	40	45	0.070	0.070	0.070	23.0980
14	250	63	112	40	55	0.045	0.050	0.050	26.3047
15	250	63	112	40	65	0.065	0.065	0.075	23.2867
16	250	84	56	55	45	0.080	0.080	0.075	22.1171
17	250	84	56	55	55	0.070	0.075	0.075	22.6895
18	250	84	56	55	65	0.040	0.045	0.040	27.5903
19	270	42	112	55	45	0.055	0.055	0.050	25.4516
20	270	42	112	55	55	0.075	0.075	0.075	22.4988
21	270	42	112	55	65	0.065	0.055	0.060	24.4169
22	270	63	56	70	45	0.060	0.060	0.060	24.4370
23	270	63	56	70	55	0.045	0.060	0.055	25.4011
24	270	63	56	70	65	0.065	0.075	0.060	23.4840
25	270	84	84	40	45	0.070	0.060	0.060	23.9434
26	270	84	84	40	55	0.060	0.065	0.065	23.9613
27	270	84	84	40	65	0.075	0.070	0.075	22.6894

**Table 4.5 Flash defect response table for S/N ratio (smaller is Better)**

Level	Melting temperature	Holding pressure	Injection pressure	Injection speed	Cooling time
1	24.44	24.53	24.19	23.92	24.43
2	24.61	24.57	24.68	24.43	24.37
3	24.03	23.97	24.20	24.72	24.37
Delta( $\Delta$ )	0.58	0.60	0.49	0.79	0.03
Rank	3	2	4	1	5

The parameter having higher rank equivalent to higher delta value means that this factor contributes to the PIM process more effective than other lower rank parameters. The result in Table 4.5 shows that the optimal parameter setting are melting Temperature: 250, holding pressure: 63, Injection Pressure: 84 injection Speed: 70 and cooling time 45. Contribution of factors arranged by delta ( $\Delta$ ).

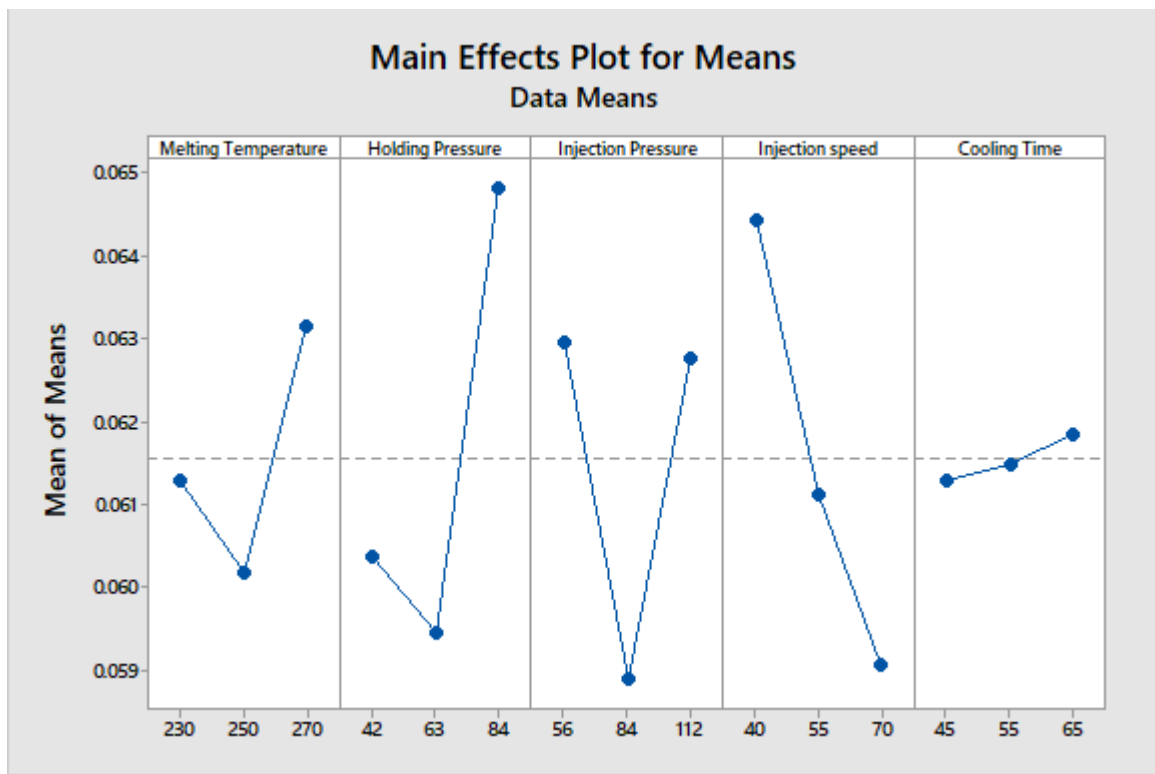


**Figure 4.4 Flash defect main effect plot for S/N ratio**

**Table 4.6 Flash defect response table for main ratio (smaller is Better)**

Level	Melting temperature	Holding pressure	Injection pressure	Injection speed	Cooling time
1	0.06130	0.06037	0.06296	0.06444	0.06130
2	0.06019	0.05944	0.05889	0.06111	0.06148
3	0.06315	0.06481	0.06278	0.05907	0.06185
Delta( $\Delta$ )	0.00296	0.00537	0.00407	0.00537	0.00056
Rank	4	1	3	2	5

From Table 4.6 shows that mean of flash defect of each parameters, this shows holding pressure have higher average flash defect and cooling time have lower average flash defect. The parameter having higher rank equivalent to higher delta value means that this factor have higher contribution of flash defect it takes more effective than other lower rank parameters. The result in Table 4.6 shows that the optimal parameter setting based on average contribution of flash defect are, holding pressure, injection Speed, Injection Pressure, melting Temperature and cooling time contribution of factors arranged by delta ( $\Delta$ ).



**Figure 4.5 Flash defect main effect plot for means**

From main effect plot for S/N ratio in Figure 4.4 and main effect plot for means data Figure 4.5 conclude the following for flash defect optimization

- Melting temperature at 250°C has a higher signal to noise ratio and lower average flash defect. This means that 250°C safely recommended for melting temperature.
- Holding pressure at 63MPa has a higher signal to noise ratio and main effect plot shows a lower average flash defect. This means that 63MPa safely recommended for melting temperature.

- Injection pressure 84MPa has a higher signal to noise ratio and main effect plot shows a lower average flash defect. This means that 84MPa safely recommended for injection pressure.
- Injection speed at 70rpm has a higher signal to noise ratio and main effect plot shows a lower average flash defect. This means that 70rpm safely recommended for injection pressure.
- Cooling time 60sec have a higher signal to noise ratio the men effect shows higher average flash defect .but, cooling time has a less impact on flash defect it is preferable to select from the optimum setting from main so cooling time at 45sec have a lower average flash defect. This means that cooling time at 45sec are safely recommended.

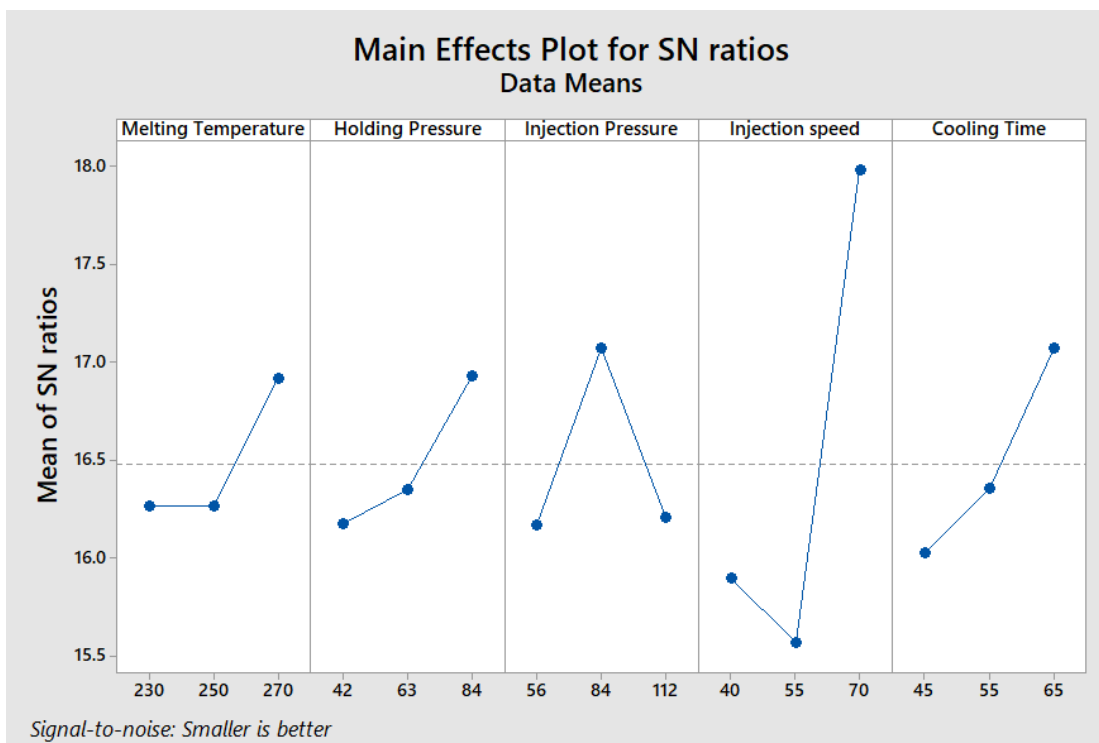
**Table 4.7 Taguchi orthogonal array result for short shot**

Run	M.T	H.P	I.P	I.S	C.T	Result 1	Result 2	Result 3	S/N ratio
1	230	42	56	40	45	0.185	0.185	0.185	14.6566
2	230	42	56	40	55	0.185	0.190	0.185	14.5780
3	230	42	56	40	65	0.160	0.160	0.160	15.9176
4	230	63	84	55	45	0.165	0.165	0.160	15.7376
5	230	63	84	55	55	0.155	0.145	0.160	16.2801
6	230	63	84	55	65	0.170	0.175	0.165	15.3885
7	230	84	112	70	45	0.200	0.195	0.200	14.0515
8	230	84	112	70	55	0.110	0.105	0.115	19.1662
9	230	84	112	70	65	0.090	0.095	0.095	20.5965
10	250	42	84	70	45	0.120	0.125	0.125	18.1768
11	250	42	84	70	55	0.185	0.180	0.185	14.7345
12	250	42	84	70	65	0.085	0.085	0.090	21.2397
13	250	63	112	40	45	0.180	0.185	0.180	14.8138
14	250	63	112	40	55	0.145	0.150	0.150	16.5741
15	250	63	112	40	65	0.190	0.195	0.185	14.4229
16	250	84	56	55	45	0.170	0.180	0.175	15.1369
17	250	84	56	55	55	0.155	0.175	0.175	15.4630
18	250	84	56	55	65	0.160	0.165	0.160	15.8267
19	270	42	112	55	45	0.155	0.155	0.155	16.1934
20	270	42	112	55	55	0.185	0.185	0.185	14.6566
21	270	42	112	55	65	0.170	0.170	0.170	15.3910
22	270	63	56	70	45	0.115	0.115	0.115	18.7860
23	270	63	56	70	55	0.095	0.100	0.105	19.9928
24	270	63	56	70	65	0.175	0.175	0.175	15.1392
25	270	84	84	40	45	0.145	0.145	0.150	16.6723
26	270	84	84	40	55	0.160	0.165	0.165	15.7376
27	270	84	84	40	65	0.105	0.100	0.105	19.7129

**Table 4.8 Short shot response Table for S/N ratio (smaller is Better)**

Level	Melting temperature	Holding pressure	Injection pressure	Injection speed	Cooling time
1	16.26	16.17	16.17	15.90	16.02
2	16.27	16.35	17.08	15.56	16.35
3	16.92	16.93	16.21	17.99	17.07
Delta( $\Delta$ )	0.66	0.76	0.91	2.42	1.05
Rank	5	2	3	1	2

The result in Table 4.8 shows that the optimal parameter setting are melting Temperature: 270, holding pressure: 84, Injection Pressure: 84 injection Speed: 70 and cooling time 65. Contribution of factors arranged by delta values ( $\Delta$ ).

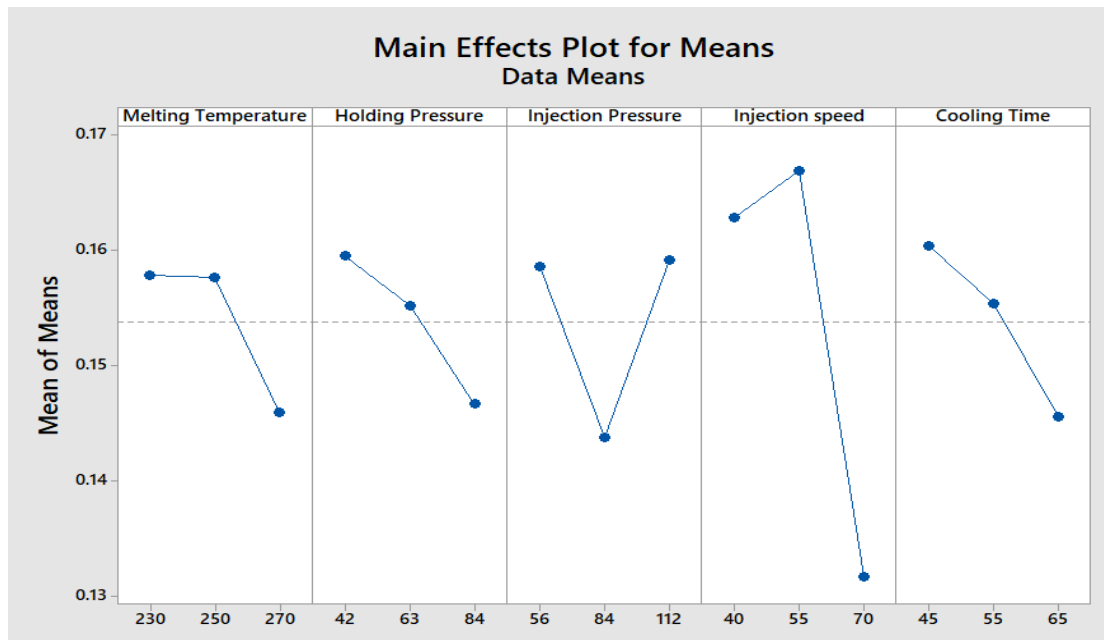


**Figure 4.6 Short shot main effect plot for S/N ratio**

**Table 4.9 Short shot Response Table for main ratio (smaller is Better)**

Level	Melting temperature	Holding pressure	Injection pressure	Injection speed	Cooling time
1	0.1578	0.1594	0.1585	0.1628	0.1604
2	0.1576	0.1552	0.1437	0.1669	0.1554
3	0.1459	0.1467	0.1591	0.1317	0.1456
Delta( $\Delta$ )	0.0119	0.0128	0.0154	0.0352	0.0148
Rank	5	4	2	1	3

From Table 4.9 shows that mean of short shot defect of each parameters, this shows injection speed have higher average short shot defect and melting temperature have lower average short shot defect. The result in Table 4.9 shows that the optimal parameter setting based on average contribution of short shot defect are injection Speed, Injection Pressure, cooling time, holding pressure and melting Temperature contribution of factors arranged by delta ( $\Delta$ ).



**Figure 4.7 Short shot defect main effect plot for means**

From main effect plot for S/N ratio in Figure 4.6 and main effect plot for means data Figure 4.7 conclude the following for short shot defect optimization

- Melting temperature at 270°C has a higher signal to noise ratio and lower average short shot defect. This means that 270°C safely recommended for melting temperature.
- Holding pressure at 84MPa has a higher signal to noise ratio and main effect plot shows a lower average short shot defect. This means that 84MPa safely recommended for melting temperature.
- Injection pressure 84MPa has a higher signal to noise ratio and main effect plot shows a lower average short shot defect. This means that 84MPa safely recommended for injection pressure.

- Injection speed at 70rpm has a higher signal to noise ratio and main effect plot shows a lower average short shot defect. This means that 70rpm safely recommended for injection pressure.
- Cooling time at 65sec has a higher signal to noise ratio and main effect plot shows a lower average short shot defect. This means that 65rpm safely recommended for injection pressure. This means that cooling time at 65sec are safely recommended.

#### **4.5 Analysis of Variance**

Analysis of variance (ANOVA) is a collection of statistical models and their associated estimation procedures (such as the "variation" among and between groups) used to analyze the differences among group means in a sample. The ANOVA is used in order to investigate the most significant factors affecting the quality of the final product. The results show the best combination of factors and levels to maximize S/N ratio, which causes less sensitivity of uncontrollable factors during production. The significant control factor for flash and short shot defect are determined using analysis of variance (ANOVA) as shown in Table 4.10 and Table 4.11. ANOVA can also provide the degree of freedom (DF), Sequential sum of squares (Seq ss) adjusted sum of squares (Adj ss), adjusting sum of square (adj Ms) and the F-statistic. The significant factor are determine by using p value.

**Table 4.10 Analysis of variance for flash defect**

<b>Source</b>	<b>DF</b>	<b>Adj SS</b>	<b>Adj MS</b>	<b>F-Value</b>	<b>P-Value</b>
Melting temperature	2	0.000013	0.000006	0.03	0.967
Holding Pressure	2	0.000119	0.000059	0.13	0.741
Injection Pressure	2	0.000096	0.000048	0.25	0.783
Injection Speed	2	0.000246	0.000123	0.63	0.543
Cooling Time	2	0.000013	0.000006	0.03	0.967
Error	16	0.003104	0.000194		
Total	26	0.003591			

From the results of ANOVA as presented Table 4.10 it, is found that injection speed have significant parameters due to the smaller the p-values than the other parameters. Moreover, holding and injection pressure has a very remarkable effect on flash defect. Although

parameters melting temperature and cooling time does not show significance effect. From table 4.10 significant factors are arranged as high to lower as follow injection speed, holding pressure, injection pressure and melting temperature and cooling time have equal value.

**Table 4.11 Analysis of variance for short shot defect**

Source	DF	Seq SS	Adj SS	Adj Ms	F-Value	P-Value
Melting temperature	2	0.000791	0.000791	0.000395	0.34	0.714
Holding Pressure	2	0.001069	0.001096	0.000534	0.47	0.636
Injection Pressure	2	0.001146	0.001146	0.000753	0.50	0.616
Injection Speed	2	0.006496	0.006496	0.003248	2.83	0.089
Cooling Time	2	0.000941	0.000941	0.000470	0.41	0.671
Error	16	0.018376	0.018376	0.001148		
Total	26	0.028819				

The ANOVA results for short shot are given in Table 4.11 shows that injection speed have significant parameters due to the smaller the p-values than the other parameters. Hence, melting temperature, holding and injection pressure and cooling time have a very low notable effect on short shot defect. Significant factors are arranged as high to lower as follow injection speed, injection pressure, holding pressure, cooling time and melting temperature.

#### **4.6 Confirming Experiment**

The purpose of the confirming the experiments is to validate of the optimum process parameters. The optimal process parameter setting result from Taguchi analysis are verified by comparing percentage of flash and short shot defect before the experiment and after run the machine by using optimal parameter setting. From sample data in appendix 1 and 2 that is illustrated by pia chart in Figure 4.8 for flash defect and Figure 4.9 for short shot defect on plastic injection molding machine products before the experiment is conducted and Figure 4.9 for flash defect and Figure 4.11 for short shot defects in plastic injection molding machine after the experiment. In order to analyze the percentage of flash defect on plastic product, a statistical analysis was carried out using Minitab software by using the following equations.

$$\% \text{ of flash defect} = \frac{\sum \text{mass of flash defect}}{\sum \text{total mass}} * 100 \dots\dots\dots 4.2$$

$$\% \text{ of product} = \frac{\sum \text{mass of product}}{\sum \text{total mass}} * 100 \dots\dots\dots 4.3$$

$$\text{Total mass} = \sum \text{mass of product} + \sum \text{mass of flash defect} \dots\dots\dots 4.4$$

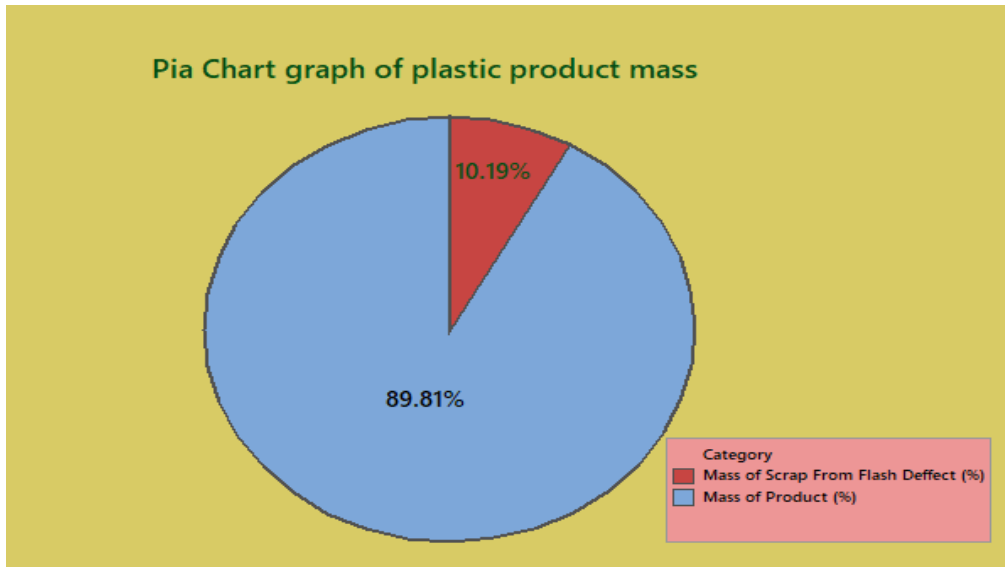


Figure 4.8 Pie chart shows flash defect on plastic injection machine before optimal setting is set

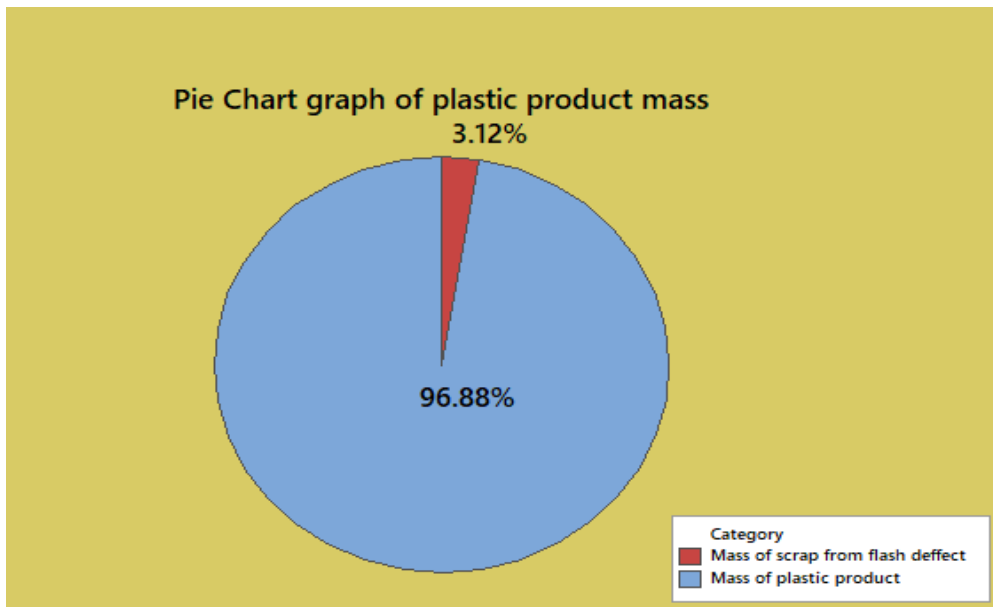


Figure 4.9 pie chart of flash defect on plastic injection molding machine after optimal setting is set

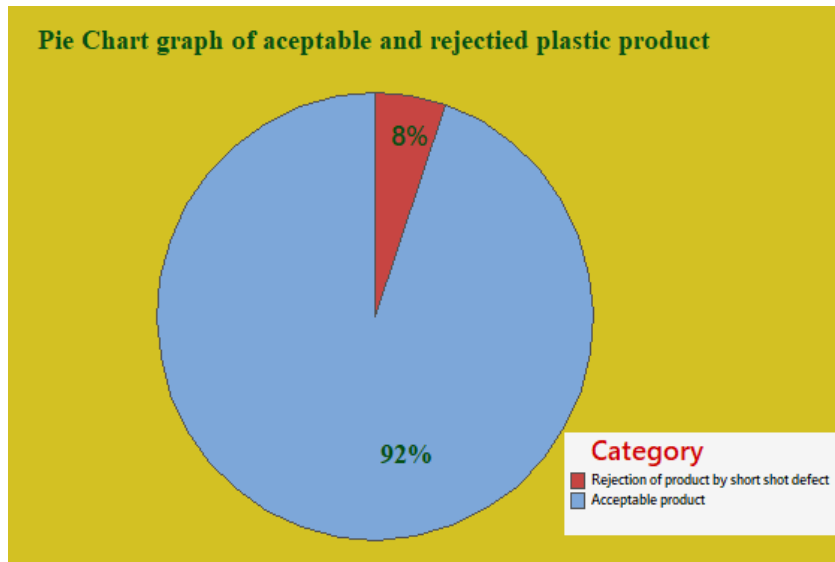


Figure 4.10 Pie chart shows short shot defect on plastic injection machine before optimal setting is set.

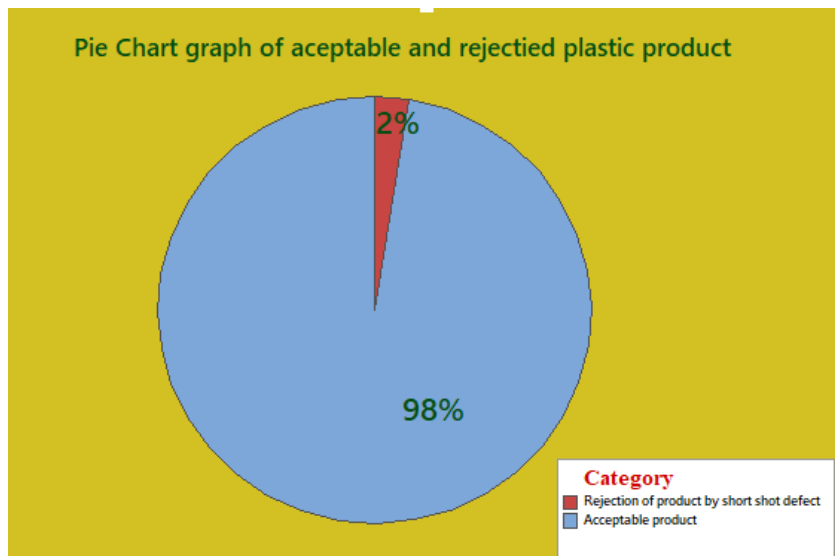


Figure 4.11 Pie chart shows short shot defect on plastic injection machine after optimal setting is set.

The aim of this sample data collection is to study and examine about the percentage of flash defect and percentage of short shot defect product rejection in plastic injection molding machine and show the feasible impact of flash and short shot defect in injection molding machine, in the quality of product and society .in addition to this it shows the link between cost of product and quality of product. In order to analyze the percentage of flash and short shot defect on plastic product, a statistical analysis was carried out using Minitab software. Sample data are guttered randomly in every 30 min interval.

Statistical analysis data gives 10.19% of polypropylene material manufactured by plastic injection molding machine are scrap caused by flash defect and 8% of the product are rejected by short shot defect it needs rework. Therefore, this work is essential to reduced flash and short shot defects on plastic injection molding machine. After applying the optimal parametric setting on plastic injection, molding machine flash defect is reduced by 7.07 % and short shot defect is reduced by 6%.

## **Chapter Five**

### **5 Conclusions and Recommendations**

#### **5.1 Conclusions**

In this study, optimization process parameters of plastic injection molding machine to reduced flash and short shot defect are investigated. The analysis was carried out in polypropylene material of P640J by using Taguchi method. The methodology of the research work have three stage, in the first stage study about failure mode of plastic product in plastic injection molding machine, select the control factors and based on the control factors and its levels select the orthogonal array. In the second stage conduct the experiment and analysis the result of experiment. At the final stage identify the significant factor using ANOVA and confirming the experimental result. The result shows that excellently agreement in Taguchi method to reduced flash and short shot defects.

Determining of optimum plastic injection molding machine is important to minimize loss. I.e. loss is not only scrap, rework or rejection but also economical drawbacks as a result of incompatible product, maintenance cost, failure cost and excessive cost of production. In the past Ameze plastic factory used trial and error method to determine the best combinations of plastic injection molding machine parameters. However, this method does not show the interaction between factors and it requires time, money and energy. However, Taguchi method has capable of determining the best combination of plastic injection molding machine process parameters with a minimum number of experiment. The main objective of this project is to investigate process parameters of plastic injection molding machine to reduced flash and short shot defect using a smallest number of trial.

In this paper work the optimal process parameters are investigated in three stages. The main objective of stage one is to identify the critical defects of plastic injection molding machine by using failure mode analysis. it study about the main defects on plastic injection molding machine in Ameze plastic factory, select the control factors, select levels of control factor and select proper orthogonal array. The aim of the second Stage is conduct and analysis the experiment. In the final stage, identify the significant factors and confirming the experiment comparing percentage of flash and short shot defect on plastic injection molding machine. Melting temperature, holding pressure, injection pressure, injection speed, and cooling time are used as a control factor and each factor have three levels. According to the Taguchi

method, recommended orthogonal array for five factor and three level is L27 orthogonal array. By using well-organized orthogonal array Minitab calculate the S/N ratio

From the S/N ratio and mine value determine the best combination of process parameters to minimize flash defects are melting temperature 250°C, Holding pressure 63MPa injection pressure 84 MPa, injection speed 70rpm and cooling time 45sec and for short shot defect melting temperature 270°C, Holding pressure 84MPa injection pressure 84 MPa, injection speed 70rpm and cooling time 65sec. From ANOVA analysis injection speed have more significant factor for flash defect, On the other hand melting temperature and cooling time have less significant effect. Injection speed have significant parameters in short shot defect than the other parameters. Hence, melting temperature, holding and injection pressure and cooling time have a very low notable effect on short shot defect

According to the sample data flash defect are reduced by 7.07% and short shot is reduced by 6% so the optimal process parameters are suitable for reducing flash and short shot defects. This shows that the proposed optimization technique, control factors and its levels are successfully achieved the goal of this theses.

From industrial aspect of this work the industry have highly promoted from cost and production rate this means the total production of Ameze plastic factory are 300 plastic laundry buckets per day from this 36.57% of plastic material requires rework that is scrap from flash and short shot defect. After this paper work, only 11.64 % of plastic material needs rework. From this analytical data Ameze plastic factory reduced the cost of product manufacturing cost, workers, machine cost, operation cost.

## **5.2 Recommendations and Future work**

The study was successfully found the optimal parameters setting for plastic injection molding Machine. The process parameters are selected based on machine manual, literature review, polypropylene p640J property, brainstorming and discussion with machine experts. holding time, molding temperature are not considered in this investigation ,in the future work holding time and molding temperature are recommended to reduced flash and short shot defect. In addition, recommend comparing of this experimental data and plastic injection molding simulation software (such as mold flow and solid work plastic).

## References

- López, A., Aisa, J., Martinez, A., & Mercado, D. (2016). Injection moulding parameters influence on weight quality of complex parts by means of DOE application: Case study. *Measurement*, 90, 349-356.
- Kamoun, A., Jaziri, M., & Chaabouni, M. (2009). The use of the simplex method and its derivatives to the on-line optimization of the parameters of an injection moulding process. *Chemometrics and Intelligent Laboratory Systems*, 96(2), 117-122..
- Antony, J. (2003). *Design of Experiments for Engineers and Scientists*. Elsevier Science & Technology Books.
- Askeland, D. (1998). *The Science and Engineering of materials* . United Kingdom: Nelson Thomes Ltd.
- Kc, B., Faruk, O., Agnelli, J. A. M., Leao, A. L., Tjong, J., & Sain, M. (2016). Sisal-glass fiber hybrid biocomposite: Optimization of injection molding parameters using Taguchi method for reducing shrinkage. *Composites Part A: Applied Science and Manufacturing*, 83, 152-159.
- Tranter, J. B., Refalo, P., & Rochman, A. (2017). Towards sustainable injection molding of ABS plastic products. *Journal of Manufacturing Processes*, 29, 399-406.
- Bagchi, T. P. (1993). *TAGUCHI METHODS EXPLAINED Practical Steps to Robust Design*. New Delhi: Prentice-Hall of India Private Limited.
- Benyounis, S. E. (2016). Review of recent developments in injection molding process for polymeric materials. *Reference module in materials science and materials engineering* .
- Montgomery, D. C. (2001). *Design and analysis of experiments* John Wiley. *New York*.
- Callister Jr, W. D., & Rethwisch, D. G. (2012). *Fundamentals of materials science and engineering: an integrated approach*. John Wiley & Sons.
- Campo, E. A. (2006). *The complete part design handbook*. Hanser, Munich.

- Chen, C. P., Chuang, M. T., Hsiao, Y. H., Yang, Y. K., & Tsai, C. H. (2009). Simulation and experimental study in determining injection molding process parameters for thin-shell plastic parts via design of experiments analysis. *Expert Systems with Applications*, 36(7), 10752-10759.
- Gu, F., Hall, P., Miles, N. J., Ding, Q., & Wu, T. (2014). Improvement of mechanical properties of recycled plastic blends via optimizing processing parameters using the Taguchi method and principal component analysis. *Materials & Design (1980-2015)*, 62, 189-198.
- Gordon Jr, M. J. (2010). *Total quality process control for injection molding* (Vol. 5). John Wiley & Sons.
- Han, C. D. (2007). *Rheology and processing of polymeric materials: Volume 1: Polymer Rheology* (Vol. 1). Oxford University Press on Demand.
- Karasu, M. K., Cakmakci, M., Cakiroglu, M. B., Ayva, E., & Demirel-Ortabas, N. (2014). Improvement of changeover times via Taguchi empowered SMED/case study on injection molding production. *Measurement*, 47, 741-748.
- Chen, W. C., & Kurniawan, D. (2014). Process parameters optimization for multiple quality characteristics in plastic injection molding using Taguchi method, BPNN, GA, and hybrid PSO-GA. *International journal of precision engineering and manufacturing*, 15(8), 1583-1593.
- Othman, M. H., Hasan, S., Khamis, S. Z., Ibrahim, M. H. I., & Amin, S. Y. M. (2017). Optimisation of Injection Moulding Parameter towards Shrinkage and Warpage for Polypropylene-Nanoclay-Gigantochloa Scortechinii Nanocomposites. *Procedia engineering*, 184, 673-680.
- Tian, M., Gong, X., Yin, L., Li, H., Ming, W., Zhang, Z., & Chen, J. (2017). Multi-objective optimization of injection molding process parameters in two stages for multiple quality characteristics and energy efficiency using Taguchi method and NSGA-II. *The International Journal of Advanced Manufacturing Technology*, 89(1-4), 241-254.
- Huang, M. L., Hung, Y. H., & Yang, Z. S. (2016). Validation of a method using Taguchi, response surface, neural network, and genetic algorithm. *Measurement*, 94, 284-294.
- Ohring, M. (1995). *Engineering materials science*. Elsevier.

- Öktem, H. (2012). Optimum process conditions on shrinkage of an injected-molded part of DVD-ROM cover using Taguchi robust method. *The International Journal of Advanced Manufacturing Technology*, 61(5-8), 519-528.
- Ozcelik, B., Ozbay, A., & Demirbas, E. (2010). Influence of injection parameters and mold materials on mechanical properties of ABS in plastic injection molding. *International Communications in Heat and Mass Transfer*, 37(9), 1359-1365.
- JMP, A., & Proust, M. (2010). Design of experiments guide. Cary, NC: SAS Institute Inc.
- Roy, R. (1990). *A primer on the taguchi method*. new york: van nostrand reinhold.
- Roy, R. (2001). *design of experments using the taguchi approach 16 steps to product and process improvement*. New York: John Wiley and sons, Inc.
- Stephen, L. (1993). *Fundamental Principles of polymeric materials*. new york: john wilen and sons,inc.
- Strong, A. (2006). *plastic material and procesing*. pearson education,inc,upper saddle river.
- Erzurumlu, T., & Ozcelik, B. (2006). Minimization of warpage and sink index in injection-molded thermoplastic parts using Taguchi optimization method. *Materials & design*, 27(10), 853-861.
- Wang, Y. Q., Kim, J. G., & Song, J. I. (2014). Optimization of plastic injection molding process parameters for manufacturing a brake booster valve body. *Materials & Design (1980-2015)*, 56, 313-317.
- Xie, X. C., Lin, C. G., Jia, C. C., & Cao, R. J. (2015). Effects of process parameters on quality of ultrafine WC/12Co injection molded compacts. *International Journal of Refractory Metals and Hard Materials*, 48, 305-311.
- Wang, X., Gu, J., Shen, C., & Wang, X. (2015). Warpage optimization with dynamic injection molding technology and sequential optimization method. *The International Journal of Advanced Manufacturing Technology*, 78(1-4), 177-187.
- Yin, F., Mao, H., & Hua, L. (2011). A hybrid of back propagation neural network and genetic algorithm for optimization of injection molding process parameters. *Materials & Design*, 32(6), 3457-3464

## Appendix 1

### Sample data for flash defect

Scrap from flash defect before conducting the experiment in plastic injection molding machine p 7800 in kg

0.770	0.775	0.780	0.790	0.775	0.775	0.780	0.795	0.785	0.785
0.765	0.770	0.775	0.785	0.775	0.795	0.785	0.775	0.775	0.775
0.785	0.775	0.775	0.770	0.785	0.775	0.790	0.765	0.785	0.785
0.785	0.795	0.790	0.790	0.790	0.795	0.785	0.765	0.785	0.795
0.785	0.775	0.785	0.785	0.785	0.775	0.770	0.775	0.775	0.770
0.785	0.765	0.780	0.785	0.790	0.785	0.795	0.765	0.785	0.795
0.785	0.785	0.775	0.775	0.770	0.770	0.775	0.765	0.770	0.765
0.775	0.775	0.775	0.770	0.775	0.785	0.795	0.775	0.770	0.770
0.770	0.775	0.775	0.795	0.795	0.790	0.790	0.785	0.775	0.785
0.785	0.785	0.785	0.785	0.780	0.775	0.775	0.770	0.750	0.750

### Sample data for flash defect

Scrap from flash defect after conducting the experiment in plastic injection molding machine p 7800 in kg

0.735	0.725	0.725	0.715	0.745	0.715	0.715	0.720	0.715	0.735	0.725	0.725
0.715	0.715	0.725	0.735	0.715	0.725	0.745	0.725	0.715	0.725	0.735	0.735
0.725	0.710	0.715	0.700	0.715	0.725	0.710	0.725	0.715	0.725	0.715	0.715
0.720	0.735	0.725	0.715	0.715	0.725	0.725	0.715	0.725	0.710	0.710	0.710
0.715	0.715	0.720	0.725	0.735	0.740	0.715	0.725	0.725	0.725	0.725	0.725
0.715	0.720	0.740	0.715	0.740	0.710	0.720	0.715	0.720	0.725	0.715	0.715
0.730	0.730	0.715	0.715	0.730	0.740	0.725	0.725	0.715	0.735	0.715	0.715
0.725	0.710	0.725	0.740	0.750	0.720	0.725	0.720	0.725	0.715	0.720	0.720
0.710	0.715	0.740	0.720	0.725	0.735	0.720	0.720	0.710	0.710	0.720	0.720

## Appendix 2

### Sample data for short shot defect

Rejection of plastic product by short shot defect before conducting the experiment in plastic injection molding machine p 10,000 in kg

2.185	2.190	2.185	2.050	2.185	2.005	2.185	2.185	2.180	2.185
2.180	1.995	2.185	2.185	2.190	2.190	2.185	2.185	2.185	2.180
2.190	2.185	2.185	2.180	2.190	2.185	2.190	2.180	2.180	2.180
2.185	2.180	2.180	2.185	2.185	2.185	2.185	2.190	2.185	2.185
2.185	2.075	2.185	2.185	2.185	2.005	2.180	2.185	2.185	2.180
2.185	2.190	2.180	2.185	2.190	2.185	1.185	2.185	2.185	2.190
2.185	2.185	2.180	2.180	2.190	2.185	2.185	2.190	2.180	2.185
2.185	2.180	2.180	2.180	2.075	2.185	2.190	2.180	2.180	2.185
2.190	2.185	2.185	2.190	2.180	2.190	2.190	2.185	2.185	2.185
2.185	2.185	2.185	2.190	2.180	2.010	2.180	2.185	2.180	2.180

Rejection of plastic product by short shot defect before conducting the experiment in plastic injection molding machine p 10,000 in kg

2.185	2.185	2.190	2.180	2.185	2.185	2.180	2.185	2.190	2.185
2.060	2.185	2.190	2.185	2.185	2.180	2.185	2.180	2.185	2.185
2.190	2.180	2.190	2.185	2.185	2.185	2.180	2.190	2.185	2.185
2.180	2.190	2.185	2.190	2.180	2.180	2.180	2.185	2.185	2.155
2.180	2.190	2.185	2.185	2.185	2.180	2.185	2.185	2.185	2.185
2.185	2.185	2.190	2.185	2.185	2.185	2.180	2.185	2.190	2.190
2.185	2.185	2.190	2.185	2.185	2.190	2.185	2.185	2.180	2.180
2.190	2.185	2.185	2.190	2.180	2.185	2.185	2.180	2.180	2.180
2.185	2.185	2.190	2.180	2.180	2.185	2.190	2.185	2.185	2.190
2.180	2.190	2.190	2.185	2.185	2.185	2.185	2.185	2.185	2.190

### **Appendix 3**

Figure 28 photo during Experiment



