

**Application of Six Sigma Methodology and Design of
Experiments for Process Improvement in Industrial
Companies**

By :

Hanaa Soliman AboHashima

A thesis submitted in partial fulfillment of Master Degree in
Industrial Engineering

Supervisors:

Professor Hazem Aly Attia

Associate Professor Mohamed Fahmy Aly

Dr. Ahmed Nabil Mohib

Approved by:

Professor Mohamed Hassan Gadallah

Professor Hazem Aly Attia

Associate Professor Mohamed Fahmy Aly

Associate Professor Islam Helaly Abed El Azez

2016

Abstract

Six Sigma is regarded as a well-structured methodology for improving the quality of processes and products. The prime objective of Six Sigma is reducing defects by reducing variability in the system. Six Sigma and Design of Experiments (DOE) are used to verify the cause-and-effect relationships between the parameters critical to quality (CTQs) and the critical few factors that drive the process under study.

Objectives of the present work are three folds; the first is to integrate Six Sigma methodology with Design of Experiments as a model for quality improvement. The second is to explore this developed model for the improvement of the quality of plastic injection molding process. This work is applied at the international Engineering union company (IEUC). The Third objective is to explore the Mold Flow simulation software for the simulation and improvement of the plastic injection process.

During this work the Six Sigma DMAIC methodology is applied with many tools for the improvement process. Project charter and SIPOC tools are applied in the define phase with Voice of Customer (VOC) and critical to quality (CTQs). During the measure phase the Sigma level is computed and Pareto principle is applied to find the priority for improvement. During the analyze phase ways to reduce defects were identified .During the Improve phase the DOE is introduced to find the required experiments, factors and its levels that control the injection molding parameters.

Analysis of Variance (ANOVA) method is used for identifying the significant factors affecting the plastic molding process. One of the main defects in the plastic injection molding process is incomplete filling. For this type of defect the significant factors are injection pressure, melting temperature, injection speed, packing pressure.

Mold Flow simulation software used for analysis and simulation of injection molding process. Many runs has performed to find the best parameters for minimizing the defect percentage. Volumetric shrinkage is one of the important type of defects of the injection molding process. Analysis of this type of defect is performed using Mold Flow simulation software integrated with Taguchi method and ANOVA. The Mold Flow simulation showed that the significant factors affecting quality of the product are the melting temperature and mold temperature.

Acknowledgement

I would like to thank Allah for giving us capability and opportunity to do this work.

The deepest appreciation goes to my supervisors **Dr. Mohamed Fahmy Ali , Dr. Ahmed Mohib and Dr. Hazem Ali Attia** The support and guidance I receive from them helps me to me to accomplish this work.

It is most important to thank my Small family, My Husband(**Eng. Hamzawy Moaaz**) and My daughter (**Haneen**) and Her grand Mother

It is also most important to thank my Big family Parents (Dad&Mam), Brother and Sisters (**Mrs. Mervat Soliman ,My uncle Gooda Saber,Mr. Azmy Soliman and his wife, Mr. Ramadan Soliman and his wife, Mr. Salama and his wife , Mr. Ahmed and his wife, Mr. Mohammed Soliman, Mrs.Olfat, Mr. Mohsen Mohammed**)and my best friend **Eng.Neamat Gamal** for helping me to finish this work . Thank you.

I express my sincere thanks to all staff of industrial Engineering department Fayoum university Especially **Dr. Ahmed Shaban** for helping me to publish my first research.

Thanks also giving to all staff of International Engineering Union Company in the Six of October City especially **Eng Mahmoud Fawzy** for their great efforts to accomplish this work.

Content

Subject	Pag. No
Chapter 1: Introduction & Literature Review	1
1.1 Introduction	1
1.2 Thesis Organization	2
1.3 Literature Review	3
1.3.1 Six Sigma Methodology	3
1.3.2 Six Sigma success factors	6
1.3.3 Six Sigma project selection	7
1.3.4 Six Sigma applications	8
1.3.5 Design of Experiments (DOE) & Injection molding	١٣
1.4 Research objectives	1٤
Chapter 2: Six Sigma Methodologies & DOE	15
2.1 Six Sigma Methodology	1٥
2.1.٢ Six Sigma Approach	1٦
2.1.3 DMAIC	١٧
2.1.٤ Six Sigma Team Structure	٢٠
2.2 Design of Experiments (DOE)	٢٠
2.2.1 Guidelines for Designing Experiments	2١
2.2.2 The Taguchi Method	2٣
2. 3 Plastic Injection Molding Process	2٥
2.3.١ Egyptian Plastics Industry	٢٥
2.3.٢ Methods of Manufacturing Plastics	2٦
2.3.٣ Injection Molding Process	2٦
2.3.٣.1 Injection Machine	٢٨

2.3.3.2 Injection Molds	30
2.3.3.3 Plastic Material	32
2.3.4 The quality of Plastic injection molded parts and Common Defects	33
2.3.4.1. Molding flash	34
2.3.4.2. Sink mark and void problems	35
2.3.4.3 Molding high volumetric shrinkage	37
2.3.4.4 Molding Unbalanced flow	37
2.3.4.5 Molding crack	38
2.3.4.6 Molding delamination	39
2.3.5.7 Warpage problems	39
2.3.5.8 Molding short shot problems	41
Chapter 3: Application of Six Sigma	43
Methodology to a Typical Plastics Injection Plant (Case Study)	
3.1 Introduction	43
3.1.1 Study site	43
3.2 Six Sigma Model	44
3.3 DMAIC Process	46
3.3.1 Define Phase	46
3.3.2 Measure Phase	50
3.3.3 Analyze Phase	54
3.3.4 Improve Phase	60
3.3.5. Control phase	66
3.4 Experimental Results	67
3.4.1 Experimental work	69
3.4.1.1 The main factors and their levels	69
3.4.1.2 Signal to noise ratio analysis and results	70

3.4.1.3 ANOVA results of incomplete filling defect	74
3.5. Improvement Results	81
Chapter 4:Analysis of Injection molding Defects	83
Using Moldflow Simulation	
4.1 Moldflow validation	84
4.2 Simulation and DOE approach	86
4.3 Injection molding	87
4.3.1 Defect analysis	88
4.4 Experimental work on volumetric shrinkage (container 2.25 Ltr)	89
4.4.1 The experimental results using Mold flow simulation	91
4.4.2 ANOVA for mean volumetric shrinkage	95
4.4.3 ANOVA with interactions for STD for Volumetric shrinkage	98
4.4.4 Changing the thickness of container to 2 mm	99
4.5 Final Results	107
Chapter 5 Conclusion & Future Work	108
5.2 Conclusion	109
5.3. Future work and Limitations	110
References	111

List of Tables

Table	Pag. No
Table 2.1 Yield Conversion Table	۱۹
Table 3.1 Project Charter	47
Table 3.2 VOC and CTQ'S	49
Table 3.3 Process SIPOC	50
Table 3.4 The total defects in the last six months in 2014	52
Table 3.5 Different container products and its amount in the last six month	52
Table 3.6 Ltr container defects in Kg and 2.25 Ltr container defects in the last six months in 2014	53
Table 3.7 Quantity of defective in container 2.25 and 1 Ltr	56
Table 3.8 Amount of defects on the two machines	60
Table 3.9 Moplen EP548U resin technical data sheet	63
Table 3.10 The L16 (2 ⁴) array	66
Table 3.11 Parameters and their levels	71
Table 3.12 Summary of results of tests and S/N values for inverted label defect	72
Table 3.13 Response table for means for incomplete filling defect	77
Table 3.14 Response table for Signal to noise ratios smaller is better for incomplete filling defect	74
Table 3.15 Degree of freedom	77
Table. 3.16 ANOVA table for incomplete filling defect	78
Table 3.17 : ANOVA table for STD of incomplete filling	80
Table 3.18 : ANOVA for S/N of incomplete filling	81
Table 3.19 The factor that affect the Incomplete filling defect	81
Table 3.20 Defected quantity before and after the improvement	83
Table 4.1 Parameters and their levels	90
Table 4.2 Summary of results of tests and S/N values	92
Table 4.3 Response table for signal to noise ratios smaller is better for volumetric shrinkage	94

Table 4.4 Response table for means for volumetric Shrinkage	95
Table 4.5 ANOVA table for volumetric shrinkage	97
Table 4.6 ANOVA table for STD of volumetric shrinkage	99
Table 4.7 Summary of results of tests and S/N values	100
Table 4.8 ANOVA table for volumetric shrinkage	105
Table 4.1 Defected quantity before and after improvement	107

List of Figures

Figure	Pag. No
Fig. 2.1 A schematic representation for Injection molding cycle	२ॷ
Fig. 2.2 General layout for Injection-molding machine	२ॡ
Fig.2.3 A schematic representation for the injection system mechanism	२३
Fig. 2.4 Solid Model of Mould Die and Exploded View	३१
Fig. 2.5 The target quality	3ॢ
Fig. 2.6 Flash defect shape in plastic molding injection	3ॢ
Fig. 2.7 Sink marks defect shape in plastic molding injection	3।
Fig. 2.8: Warpage defect shape in plastic molding injection	4०
Fig 2.9 Incomplete filling defect shapes in plastic molding injection	4१
Fig. 3.1 Proposed Six Sigma implementation model	45
Fig. 3.2 Quantity of defects for the working products	53
Fig. 3.3 Pareto Diagram of defects type in container 2.25 Ltr	57
Fig. 3.4 Pareto Diagram of defect types in container 1 Ltr	57
Fig. 3.5 Different shapes of the inverted	58
Fig. 3.6 Cause and effect diagram for the causes of defects	59
Fig. 3.7 label length exceeds the ordinary length	59
Fig. 3.8 The standard Label design	62
Fig. 3.9 The first new label design	62
Fig. 3.10 The second new Label design	62
Fig. 3.11 Main effects plot for Mean incomplete filling defect	73
Fig. 3.12 Main effects plot for SN ratio for incomplete filling defect	73
Fig. 3.13 Plot of residuals for Incomplete filling	75
Fig. 3.14 Normal probability plot of residuals from incomplete filling experiments	76
Fig. 3.15 Pareto chart of ANOVA results for the significant factors affecting on mean incomplete filling	79
Fig. 3.16 Defective quantity Manner	83
Fig. 4.1 the results of solving example Pujari .et al. (2015)	85
Fig. 4.2 Flow chart for the simulation optimization steps applied in	87

this study

Fig. 4.3 Filling pattern of the molten plastic flow for container 2.25 (a) 22% filling and (b) 69% filling stage.	89
Fig.4.4 a, b, c Screen shout for three result	90,91
Fig.4.5 Main effects plot for volumetric shrinkage	93
Fig.4.6 Main effects plot for SN ratio for volumetric shrinkage	94
Fig.4.7 Plot of residuals for volumetric shrinkage	96
Fig.4.8 Normal probability plot of residuals from the volumetric shrinkage experiments	96
Fig. 4.9 Pareto chart for ANOVA results for the significant factors affecting on mean incomplete filling	98
Fig. 4.10 a, b, c Screen shout for three result	101,102
Fig. 4.11 Main effects plot for volumetric shrinkage at thickness 2mm	102
Fig.4.12 Main effects plot for SN ratio for volumetric shrinkage at thickness 2mm	103
Fig. 4.13 Normal probability plot of residuals from the volumetric shrinkage experiments at thickness 2mm	104
Fig. 4.14 Air trap problems in container 2.25at thickness 1mm	106
Fig. 4.15 Air trap problems in container 2.25at thickness 2mm	107

List of Abbreviations

DOE: Design of Experiments

DMAIC: Define, Measure, Analyze, Improve, Control

DFSS: Design for Six Sigma

CTQs: Criticals to Quality

VOC: Voice of Customer

SIPOC: Supplier, Input, Process, Output, Customer

ANOVA: Analysis of Variance

DPMO: Defect per Million Opportunities

S/N: Signal to Noise Ratio

SS: Statistical Sum

MS: Mean Square

STD: Standard Deviation