Thai Environmental Engineering Journal Vol. 35 No. 1 (2021) : 15-21
www.eeat.or.th

Application of Design of Experiments for Microwave Oven Plastic Parts Defectives Reduction

Chatpon Mongkalig
Institute of Metropolitan Development
Navamindradhiraj University, Bangkok 10300, Thailand
E-mail : chatpon@yahoo.com

Abstract

The 3R (Reduce-Reuse-Recycle) Concept is a sequence of steps on how to manage waste properly. The top priority is Reduce, which is to reduce waste generation, then Reuse, and finally Recycle. The main priority is always to reduce and prevent the waste generation from the production process (Reduce). The objective of this research is to prevent the waste generation and decrease the percentage of defectives from the injection molding process of an electrical appliances factory. Microwave ovens are the best-selling products of the case study. The nonconforming products data of the production process of microwave plastic parts was collected and analyzed. It was found that the occurrence of defectives from plastic front frame injection molding process was the most important problem. The major nonconforming problem was the abnormal plastic shape. Design of Experiments (DOE) method was applied to determine the optimal pressure and temperature levels of injection machines for defectives percentage minimization. For experimental design, a two-factor Completely Randomized Design (CRD) was generated and Analysis of Variance (ANOVA) was carried out. According to the ANOVA, pressure and temperature had a significant effect on defectives percentage. A significant interaction between the two factors was found. According to interaction plots, the optimal levels for pressure and temperature of injection molding process were 79 bar and 230 °C, respectively. Additionally, the confirmation test was conducted and it was concluded that the mean of defectives percentage produced by the optimal temperature and pressure process was significantly lower than the mean of the defectives percentage produced by the current process of the case study.

Keywords : Design of Experiments; Analysis of Variance; Nonconforming Products Reduction; Electrical Appliances

Introduction

The 3R (Reduce-Reuse-Recycle) Concept is a sequence of steps on how to manage waste properly. The top priority is Reduce, which is to reduce waste generation, then Reuse, and finally Recycle. Most of the production of waste should be reduced from the beginning. Only when the production of waste cannot be avoided, the items are reused. One of the methods of Reuse is through the upcycling process. When materials can no longer be used again, the waste is recycled, which is to be melted, chopped, and formed into a new product that might suffer a decrease in quality.

The main priority is always to reduce and prevent the waste generation from the production process (Reduce) [1]. The objective of this research is to prevent the waste generation and reduce the percentage of defectives from the injection molding process of an electrical appliances factory. Microwave ovens are the best-selling products of the electrical appliances factory. The nonconforming products data of the production process of microwave plastic parts was collected and analyzed. It was found that the occurrence of defectives from plastic front frame injection molding process was the most important problem. According to the plastic front frame injection molding process, the Pareto chart was used to analyze and display in **Figure 1**.

The Pareto chart for nonconforming parts in the plastic front frame injection molding process was shown in **Figure 1**. The most important nonconforming problem is the abnormal plastic shape (3,982 pieces or 64.1%). The second major problem is the plastic part contamination (1,782 pieces or 28.7%). Other defective parts are 446 pieces (7.2%). According to the abnormal plastic shape, the root cause is the inappropriate temperature and pressure in the microwave oven plastic front frame injection molding process. Therefore, Design of Experiments (DOE) was applied to determine the optimal level of temperature and pressure. Analysis of Variance (ANOVA) was used for the study of temperature and pressure effects on the defectives percentage from the microwave oven plastic front frame injection molding process.

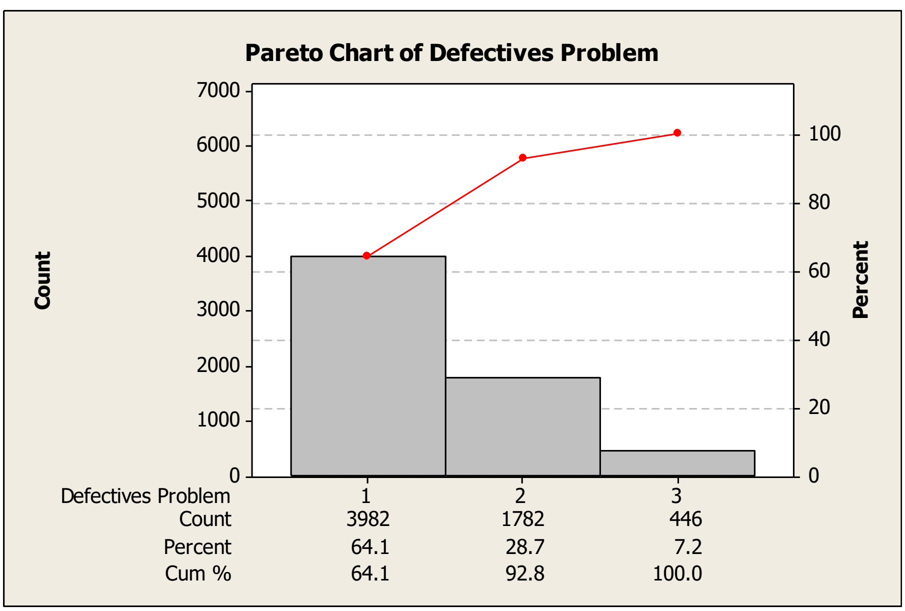

Figure 1 Pareto chart for nonconforming parts in the plastic front frame injection molding process

Methodology

Design of Experiments (DOE) mathematical methodology used for planning and conducting experiments as well as analyzing and interpreting data was obtained from the experiments [2]. It was used for conducting scientific studies of a system, process or product in which input variables (Xs) were manipulated to investigate its effects on measured response variable (Y) [3]. Design of Experiments is statistical tool deployed in various types of system, process and product design, development and optimization. It has been a very useful tool traditionally used to improve product quality and reliability [4]. The usage of DOE has been expanded across many industries as part of decision making process along with a new product development, manufacturing process and improvement. It is not used only in engineering areas but it has also been used in administration, marketing, hospitals, pharmaceutical, plastic parts, food industry [5], energy and architecture [6, 7]. Research work flow can be classified as follows:

1. State the objectives — it is a list of problems that are going to be investigated. In this research, Analysis of Variance (ANOVA) was used to study of temperature and pressure effects on the defectives percentage of the microwave oven plastic front frame injection molding process. The optimal level of temperature and pressure was experimented.

2. Response variable definition — this is measurable outcome of the experiment that is based on defined objectives. The percentage of defectives from the injection molding process is the response variable.

3. Determine factors and levels — selection of independent factors that have a significant effect on the response variable. To identify factors (temperature and pressure) that may affect the response variable (defectives percentage).

4. Determine Experimental Design type — a completely randomized design (CRD) was applied and planned.

5. Perform experiment using design matrix.

6. Data analysis using ANOVA statistical method.

7. Conclusions and recommendations including graphical representation of the results and confirmation test for validation of the results.

The two experiments for reduction of nonconforming parts for plastic front frame of microwave oven were as follows: The optimization experiment was applied to determine the optimal level of temperature and pressure in the injection molding process. Then confirmation test was conducted for validation of the results. A Completely Randomized Design (CRD) of two factors was applied for the optimization experiment. Analysis of Variance (ANOVA) was used for the analysis of temperature and pressure effects on the percentage of defectives. Before the experiments, the temperature of 240 °C and the pressure of 75 bar were used. Therefore, the unsuitable temperature and pressure levels had caused the abnormal plastic shape problem. There are four temperature levels: 215 °C, 230 °C, 240 °C, and 250 °C. There are four pressure levels: 58 bar, 67 bar, 74 bar, and 79 bar. The experimenter should carefully choose a model before collecting data. However, information may be limited, so it is also important to use the data, once it has been collected, to check the model [8]. This is typically done by residual plots. Plots of residuals typically show trends more readily than plots of the response values [9]. Therefore, normality, constant variance, and independent assumptions were checked in the model adequacy checking in **Figure 2**, **Figure 3**, and **Figure 4**.

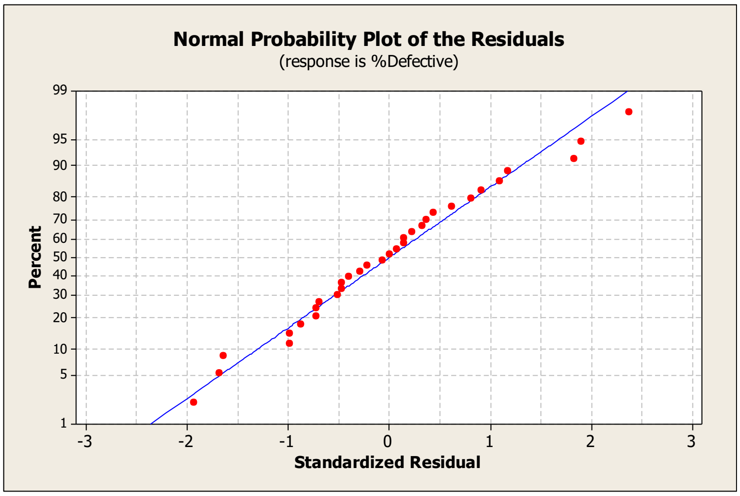

Figure 2 Normal probability plot of the residuals

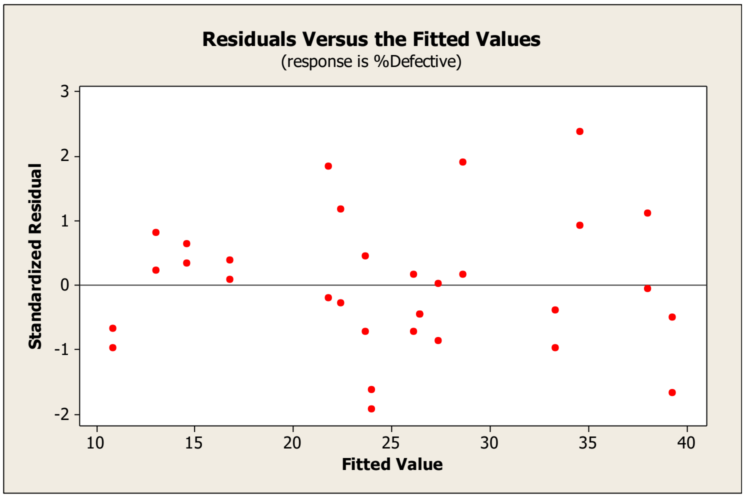

Figure 3 Constant variance assumption checking

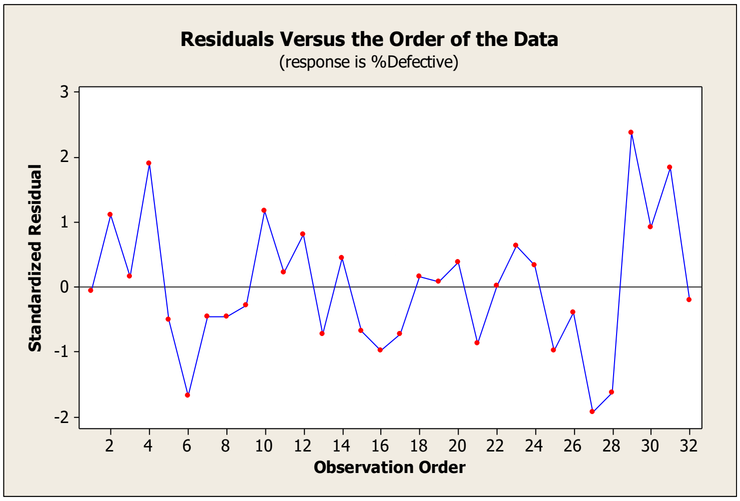

Figure 4 Residuals versus the order of the data (independence assumption)

According to the model adequacy checking, it was found that residuals were normally distributed. The variance of residuals was constant and the independence assumption was checked. Therefore, the ANOVA is suitable for the analysis of temperature and pressure effects on the percentage of defectives.

Results and Discussion

1. Optimization Experiment

According to the optimization experiment, the main effects which were temperature and pressure had a significant effect on the defectives percentage. Additionally, the interaction effect had a significant effect on the response variable as shown in **Table 1**.

Interaction plot for defectives percentage is shown in **Figure 5**. The optimal level of temperature is 230 °C. The most appropriate level of pressure is 79 bar.

2. Confirmation Test

We needed to execute the test again to confirm that whether the defectives percentage is significantly reduced. The optimal level factor (230 °C and 79 bar) was compared with the current level factor (240 °C and 75 bar). The Two-Sample T-Test was applied for the confirmation test [10]. The equality of variances was tested. It was found that the two population variances were not statistically different. According to the confirmation test as shown in **Table 2**, the T-Value was 26.56 and the P-Value was 0.000. Therefore, the mean of defectives percentage produced by the optimal temperature and pressure process was significantly lower than the mean of defectives percentage produced by the current process of the case study. The estimate for difference is 6.2%.

Table 1 The two-way ANOVA table for the experiment

General Linear Model: %Defective versus Temp, Pressure

Factor	Type	Levels	Values
Temp	fixed	4	215, 230, 240, 250
Pressure	fixed	4	58, 67, 74, 79

Analysis of Variance for %Defective, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Temp	3	1184.96	1184.96	394.99	9.49	0.001
Pressure	3	1009.96	1009.96	336.65	8.09	0.002
Temp*Pressure	9	1683.01	1683.01	187.00	4.50	0.004
Error	16	665.62	665.62	41.60		
Total	31	4543.55				

S = 6.44993   R-Sq = 85.35%   R-Sq(adj) = 71.62%

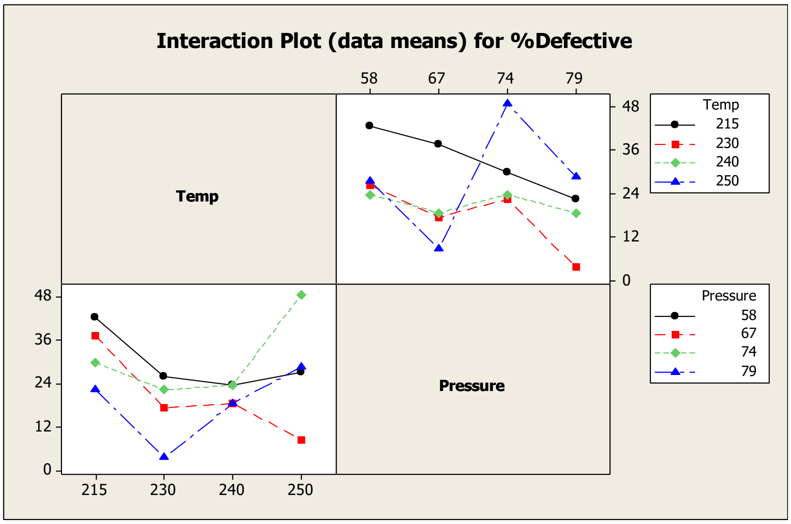

Figure 5 Interaction plot for defectives percentage

Table 2 Two-Sample T-Test was applied for the confirmation test

Two-Sample T-Test and CI: Before, Optimization

```
Two-sample T for Before vs Optimization

                N   Mean  StDev   SE Mean
Before         20  7.250  0.444    0.099
Optimization   20  1.050  0.945    0.21


Difference = mu (Before) - mu (Optimization)
Estimate for difference:  6.20000
95% CI for difference:  (5.72111, 6.67889)
T-Test of difference = 0 (vs not =): T-Value = 26.56
P-Value = 0.000 DF = 27
```

Conclusions

The defectives percentage in the injection molding process of an electrical appliances factory is the response variable of the experiment. Microwave ovens are the best-selling products of the case study. It was found that the occurrence of defectives from plastic front frame injection molding process was the most important problem. The major nonconforming problem was the abnormal plastic shape. Design of experiments method was applied to determine the optimal pressure and temperature levels of injection machines for minimization of the percentage of defectives. For experimental design, a two-factor Completely Randomized Design (CRD) was generated and Analysis of Variance (ANOVA) was carried out. According to the ANOVA, pressure and temperature had a significant effect on the percentage of defectives. A significant interaction between the two factors was found. According to interaction plots, the optimal levels of pressure and temperature of injection molding process were

79 bar and 230 °C, respectively. Additionally, the confirmation test was conducted and it can be concluded that the mean of defectives percentage produced by the optimal temperature and pressure process was significantly lower than the mean of defectives percentage produced by the current process of the case study.

References

[1] Asilahijani, H., Steiner, S.H. and MacKay, R.J. 2010. Reducing variation in an existing process with robust parameter design. Quality Engineering. 22: 30-45.

[2] Bisgaard, S. 1992. Industrial use of statistically designed experiments: Case study references and some historical anecdotes. Quality Engineering. 4: 547-562.

[3] Montgomery, D.C. 2019. Design and Analysis of Experiments. John Wiley & Sons Inc., New York.

[4] Goos, P. and Jones, B. 2011. Optimal Design of Experiments: A Case Study Approach. John Wiley & Sons Inc., New York.

[5] Yu, P., Low, M.Y. and Zhou, W. 2018. Design of experiments and regression modelling in food flavour and sensory analysis: A review. Trends in Food Science & Technology. 71: 202-215.

[6] Schlueter, A. and Geyer, P. 2018. Linking BIM and Design of Experiments to balance architectural and technical design factors for energy performance. Automation in Construction. 86: 33-43.

[7] Durakovic, B. and Torlak, M. 2017. Simulation and experimental validation of phase change material and water used as heat storage medium in window applications. Journal of Materials and Environmental Sciences. 8 (5): 1837-1846.

[8] Dean, A., Voss, D. and Draguljic, D. 2017. Design and Analysis of Experiments. Springer, New York.

[9] Montgomery, D.C. 2019. Introduction to Statistical Quality Control. John Wiley & Sons Inc., New York.

[10] Montgomery, D.C. and Runger, G.C. 2014. Applied Statistics and Probability for Engineers. John Wiley & Sons Inc., New York.