Optimizing and Modeling for Plastic Injection Molding Process using Taguchi Method

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Abstract. The objective of this work is to study process parameters of Plastic injection molding. Taguchi method, an unconventional design of experiment, is used as an approach to optimize the process parameters to improve quality characteristic of work-piece. The two responses of experiment are volume shrinkage and total displacement. Orthogonal array (L16) is used to conduct experiments. The result shows that there are three statistically significant factors out of seven factors or process parameters. Such three factors are Melt temperature, Packing time and Cooling time. Linear equations derived from experimental results are constructed and suitable conditions can be obtained from a computer based response optimizer.

1. Introduction
The Taguchi method is a useful tool to optimize designs for high performance and quality with limited experiment. As this method is based on statistics, it is prevalent in engineering, especially in the field of manufacturing process. This work, Taguchi method is used to find the suitable condition to produce the best quality of work-piece in a plastic molding process. The initial process parameters or factors studied are Filling time, Melt temperature, Mold temperature, Maximum injection pressure, Packing time, Maximum packing pressure, and Cooling time. And, uncontrollable factors studied are Air temperature and Eject temperature. The important factors were determined through analysis of variance technique (ANOVA). The linear equations were developed according to significant factors. The quality characteristics of work-piece as responses of experiment are volume shrinkage and total displacement. Then, the primary objective of this work is to develop the mathematic modeling in order to optimize and find the suitable condition that can produce the work-piece with minimum volume shrinkage and total displacement. The experimental plan based on Taguchi approach and experimental conditions are presented in later sections. The result of analysis and conclusion are provided in the last section.

2. Literature review
Taguchi method contains system design, parameters design and tolerance design to achieve a robust design in order to enhance practical product quality [1-2]. Taguchi design provides a powerful and efficient method for designing processes that operate consistently and optimally over a variety of conditions [3]. The use of Taguchi Method involves with following step [4] ; a) Identify the main function and its side effects, b) Identify the noise factors, testing conditions, and quality characteristics, c) Identify the objective function to be optimized, d) Identify the control factors and their levels, e) Select the orthogonal array matrix experiment, f) Conduct the matrix experiment, g) Analyze the data,
predict the optimum levels and performance, and h) Perform the verification experiment and plan the future action. The application of Taguchi approach is widely used in various industries [5-7].

3. Experiment plan for a plastic injection molding process

Case study conducted in this place is Injection Molding Process by using injection molding simulation software. Usually, injection molding processes in Figure 1 are as follow: Screw will rotate and retract in melting process in order to achieve setting volume of injection molding as defined. The liquid plastic is injected into the molding. Packing will be done to maintain pressure in order to compensate for shrinkage of the plastic. A cooling process of work piece is started until temperature of work piece reach to eject temperature and work piece is ejected out of the molding [8].

The purpose of the experiment is to study factors that have most effect on Volume shrinkage and Total displacement of work-piece. There are seven controllable factors of essential process parameters and two uncontrollable factors as noise parameters. The factors and their levels are presented in Table 1 below.

![Figure 1. Plastic injection mold process.](image)

| Factors                          | Level (Low) | Level (High) | Units       |
|----------------------------------|-------------|--------------|-------------|
| A. Filling time (A)              | 2           | 3            | sec.        |
| B. Melt temperature (B)          | 215         | 230          | °C          |
| C. Mold temperature              | 35          | 60           | °C          |
| D. Maximum injection pressure    | 50          | 80           | %           |
| E. Packing time                  | 4           | 6            | sec.        |
| F. Maximum packing pressure profile value | 30          | 50           | %           |
| G. Cooling time                  | 12          | 14           | sec.        |
| H. Air temperature               | 15          | 40           | °C          |
| J. Eject temperature             | 50          | 99           | °C          |

The Volume shrinkage is measured in percentage (%) and the Total displacement is measured in millimeter (mm.) are major responses of this experiment. Plastic injection computer programs are used to analyze for injection molding process to find the best value of work-piece design and measure two responses as shown in Figure 2 and 3.
4. Data analysis and result

4.1. Experiment data of orthogonal array table

In this work, the Orthogonal Arrays (L16) are used to study the seven factors and their interaction. The 16 different experimental conditions are set as shown in Table 2. Four replicates were performed in each condition and the Volume shrinkage (%) and Total displacement (mm.) are measured as responses. The overall experiments are run on 64 experiments.

Table 2. Design of experiment data.

| Runs | A | B | C | D | E | F | G | Volume Shrinkage (%) (four replicates) | Total Replacement (mm.) (four replicates) |
|------|---|---|---|---|---|---|---|----------------------------------------|---------------------------------------------|
| 1    | - | - | - | - | - | - | - | 12.146, 12.142, 10.652, 10.652 | 1.299, 1.299, 0.960, 0.960 |
| 2    | - | - | - | + | - | + | + | 08.528, 09.092, 07.540, 07.540 | 1.107, 1.193, 0.852, 0.852 |
| 3    | - | - | - | + | + | - | - | 07.769, 07.769, 06.192, 06.192 | 1.116, 1.116, 0.774, 0.774 |
| 4    | - | - | - | + | - | + | - | 09.093, 09.093, 07.541, 07.541 | 1.197, 1.197, 0.856, 0.856 |
| 5    | - | - | - | + | - | - | - | 10.213, 10.213, 08.683, 08.683 | 1.220, 1.220, 0.880, 0.880 |
| 6    | - | - | - | + | - | - | - | 08.436, 08.436, 06.872, 06.872 | 1.135, 1.135, 0.793, 0.793 |
| 7    | - | - | - | + | - | - | - | 10.135, 10.135, 08.602, 08.602 | 1.215, 1.215, 0.875, 0.875 |
| 8    | - | - | - | + | - | - | - | 14.837, 14.649, 13.199, 13.199 | 1.361, 1.359, 1.021, 1.021 |
| 9    | - | - | - | + | - | - | - | 07.545, 07.545, 05.964, 05.964 | 1.120, 1.120, 0.776, 0.776 |
| 10   | - | - | - | - | + | - | + | 08.924, 08.924, 07.369, 07.369 | 1.181, 1.181, 0.840, 0.840 |
| 11   | - | - | - | - | - | + | + | 11.072, 11.072, 09.557, 09.557 | 1.279, 1.279, 0.939, 0.939 |
| 12   | - | - | - | - | + | - | - | 08.900, 08.900, 07.344, 07.344 | 1.177, 1.177, 0.835, 0.835 |
| 13   | - | - | - | - | - | - | - | 09.862, 09.862, 08.324, 08.342 | 1.201, 1.201, 0.860, 0.860 |
| 14   | - | - | - | - | - | - | - | 13.170, 13170, 11.695, 11.695 | 1.328, 1.328, 0.989, 0.989 |
| 15   | - | - | - | - | - | - | - | 10.105, 10.105, 08.591, 08.591 | 1.210, 1.210, 0.870, 0.870 |
| 16   | - | - | - | - | - | - | - | 08.031, 08.031, 06.459, 06.459 | 1.123, 1.123, 0.781, 0.781 |

The ANOVA test, a statistical technique, is used to identify significant factors affecting those two responses. The results are shown in Figure 4 and 5. The confidential level is set at 95% (α 0.05) and the p-value below 0.05 is statistically significant.
4.2 Process modeling and optimization

The results of significant factors are used to construct a linear modeling. The equation for predicting Volume shrinkage and Total displacement are shown in equation (1) and (2), respectively.

\[ Y_1 = 9.1731 - 0.6470 B + 1.1864 E + 1.2490 G + 0.4209 E*G \] (1)

\[ Y_2 = 1.03795 - 0.01590 B + 0.04591 E + 0.05147 G - 0.00636 B*E + 0.01176 E*G \] (2)

\[ Y_1 = \text{Volume shrinkage} \, \% \]
\[ Y_2 = \text{Total displacement} \, \text{mm.} \]
\[ B = \text{Melt temperature} \]
\[ E = \text{Packing time} \]
\[ G = \text{Cooling time} \]

In order to optimize those two responses simultaneously, a response optimizer is used to facilitate the procedure. All equations are performed in computer software to select the suitable input condition to meet the target outputs as shown in Figure 6.

\[ \text{Figure 6. Response optimizer for minimizing volume shrinkage and total displacement.} \]

It is found that the minimum of volume shrinkage and total displacement can be achieved with the optimization tool. The optimal condition are low level of Melt temperature (B) and high level of Packing time (E) and Cooling time (G), which provide the 6.5% of Volume shrinkage and 0.94 mm. of Total displacement.
5. Conclusion
The application of the Taguchi method in optimization of Plastic injection molding process is introduced. The limited experiments of Orthogonal array (L16) as advantage is set to be experimental plan. The 64 experimental runs are carried out and volume shrinkage and total displacement as responses are measured. Based on ANOVA test, three factors and their interactions are found statistically significant. Such factors are Melt temperature (B), Packing time (E), Cooling time (G), interaction of B and E (BE), and interaction of E and G (EG). The designed quality of an example work-piece is set to be the minimum of volume shrinkage and total displacement as target of optimizing procedure. The solution yields Melt temperature of 215 °C, Packing time of 6 sec., and Cooling time of 14 sec. in association with volume shrinkage of 6.5% and total displacement of 0.94 mm. Then, the parameter design of Taguchi method provides a simple, systematic and efficient methodology for modeling and optimizing a case study process.

6. References
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