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Fill Time Analysis of 8 Cavities Parison Mould using Taguchi Method

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Abstract*: *In the plastic injection molding process, the optimization of the process parameters is a complex task. This paper presents the optimum conditions of the injection process for 8 cavities mold for 20g parison filled with Polyethylene Terephthalate (PET) by utilizing the Taguchi method. In the Taguchi method, the performance parameter is assumed to be the optimal parameter for injection molding process. An L16 (43) orthogonal array is considered as an experimental plan for the design parameters as suggested in Minitab version. The objective of this study is to propose an approach for efficiently optimizing injection molding parameter, i.e. fill time, with three different outputs, i.e. melting temperature, runner size and mold temperature. The illustrative application and comparison of results show that the proposed methodology outperforms the existing methods and can help injection molding process to efficiently and effectively identify optimal fill time process parameter. The result indicates the best performance for the highest contribution for each respond. This is due to the interaction of factors and it also gives the percentage contribution with 95% confidence level. The analysis using the Taguchi method showed the optimized fill time. The results show that the optimal parameters for the fill time during injection process of 8 cavities mold 20g parison is A1B1C4.

Keywords* : *Parison, Injection Moulding, Taguchi method, Performance parameter.

I. INTRODUCTION

Manufacturing of plastic material is widely used in the industries nowadays. The design plays an importance role in producing a mass production of plastic material. Plastic has provided an affordable yet robust material for many of the item used today. A plastic bottle is one of the main manufacturing processes that used the plastic material of PET as the plastic product with mass production [1]. In order to achieve these goals, the continuous development of both plastic production and process quality are two important expect that should be considered. The setup of the experiment is the most significant step to improve the product and process quality.

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In the 1950s, Ganache Taguchi, a Japanese engineer and statistician had developed tools for experimental design called the Taguchi Method. This method had improved the design of previous experiments in which many parameters can be studied with a number of experiments [2]. Taguchi's approach provides engineers/designers with a systematic and proficient approach for conducting experiments with limited statistical skills to study [3]. This method was used to analyze optimal process parameters of a single quality characteristic. This method focused on optimizing a single quality response. However, products in some processes have more than one quality response which should be considered. The Taguchi method primarily uses engineering judgment to decide optimal factor levels for multi-responses, which increases uncertainty during the decision-making process [4]. The study has been done by Kuttur [5] where he Model and multi-response optimization of pressure die casting process using Taguchi method by response surface methodology approach. In his study, the process parameters, namely, fast shot velocity, injection pressure, phase change- over point, and holding time have been considered as the input to the model. Statistical regression analysis-based techniques and Taguchi, were used to identify and analyze the effect of process parameters in the most industry [6–10].

Gang & Zhitao [11] had done research on the multiobjective optimization of process parameters for plastic injection molding via soft computing to determine the weight, volumetric shrinkage, and flash of the model. Moreover, these methodologies assume greater significance during optimization of processes having constraints with respect to raw material availability and cost [12–16].

In this paper, using the Taguchi Method approach, the process parameters for the injection molding process such as fill time, injection pressure, density and volumetric shrinkage are optimized in order to achieve the best quality of parison product.

II. METHODOLOGY

A. Material

Polyethylene Terephthalate (PET) was used as the thermoplastic polymer in this study because this material has high processability, high hardness, and stiffness. These properties of PET make the material suitable for producing drinking bottle. The structure of PET also has a good clarity and does not leave any taste in the water. Furthermore, PET has good barrier properties against carbon dioxide and oxygen. Its physical properties and chemical inertness made it suitable for food packaging applications, especially in drinks packaging.

Table I shows the mechanical properties of polyethylene terephthalate (PET) and Table II show the physical properties of polyethylene terephthalate (PET).

Table I: Mechanical Properties of Polyethylene Terephthalate (PET)

Mechanical Properties	Parameters
Coefficient of friction	0.2 - 0.4
Hardness – Rockwell	M94 - 101
Izod impact strength ($J.m^{-1}$)	13 - 35
Poisson's ratio	0.37 - 0.44 (oriented)
Tensile modulus (GPa)	2 - 4
Tensile strength (MPa)	80, for biax film 190 – 260

Table II: Physical Properties of Polyethylene Terephthalate (PET)

Physical Properties	Parameters
Melting Point	260 ˚C
Density ($g.cm^{-3}$)	1.3 - 1.4
Flammability	Self-Extinguishing
Limiting oxygen index (%)	21
Refractive index	1.58 - 1.64
Resistance to Ultraviolet	Good
Water absorption equilibrium (%)	<0.7
Water absorption over 24 hours (%)	0.1

B. Taguchi Method on Parameter Design

The analysis of optimization has been designed in a sequence of steps to ensure that data is obtained in a way that the result will lead immediately to valid statistical inferences. This research methodology is termed as Taguchi Method. Taguchi approach attempts to extract maximum important information with a minimum number of experiments [4]. Orthogonal Arrays (OA) is the analysis to identify meant for a specific number of independent design variables and levels. The analysis was conducted to understand the influence of determining the number of independent variables. This array assumes that there is no interaction between any two factors. In this study, the data was collected using an L16 orthogonal array, where the number of the level was 3 different variable having 4 set of values (Level of a factor). The L16 Orthogonal Arrays (OA) is as shown in Fig. 1. The full optimisation program of the parameters and number of an experiment for L16 are shown in Table III. Table IV shows the variable factor and level for 20g parison analysis.

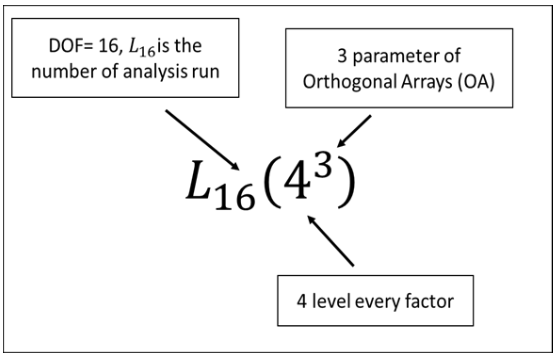

Fig. 1: L16 Orthogonal Arrays (OA)

Table III: Variable Factor and level for 20g parison

Parameter	Level			
Moulding Temperature (°C)	20	40	60	80
Runner Sizes (mm)	6	7	8	9
Melting Temperature (°C)	265	270	275	280

Table IV: Layout of L16 Orthogonal Arrays (OA)

EXP	Independence variable		
	Variable A	Variable B	Variable C
1	1	1	1
2	1	2	2
3	1	3	3
4	1	4	4
5	2	1	2
6	2	2	1
7	2	3	4
8	2	4	3
9	3	1	3
10	3	2	4
11	3	3	1
12	3	4	2
13	4	1	4
14	4	2	3
15	4	3	2
16	4	4	1

C. Calculation Method

Mean Response:

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \quad (1)$$

Standard deviation:

$$S = \sum_{i=1}^{n} \frac{(y_i - y)^2}{n-1} \quad (2)$$

The preferred parameter settings were then determined through analysis of the "signal-to-noise" (S/N) ratio where factor levels that maximize the appropriate S/N ratio were at optimal. There are three standard types of S/N ratios depending on the desired performance response,

Smaller the better (for making the system response as small as possible):

$$SN_S = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (3)$$

Larger the better (for making the system response as large as possible):

$$SN_L = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2}\right) \quad (4)$$

III. RESULT AND DISCUSSION

The signal to noise ratio (S/N) and the optimum based on smaller the better were determined. An optimal process window was determined first by inputting the factor such as mold temperature (°C), runner size (mm) and melting temperature (°C) into the table. Several injection trials were run according to the orthogonal array arrangement to estimate the responding variable. Table V shows the orthogonal array of L_{16} for the fill time analysis to determine the sum $\sum$ of the signal to noise ratio and the optimum performance range $\overline{T}$ for the S/N ratio was calculated. This result was used to determine the optimum parameter for the fill time.

Table V: Experimental Result of Fill Time and S/N Ratio

Exp	Independence variable			Respond	Signal to noise ratio (S/N) (dB)
	Mould Temperature (°C)	Runner Size (mm)	Melting Temperature (°C)		
1	20	6	265	0.6520	3.715048
2	20	7	270	0.5273	5.558845
3	20	8	275	0.5489	5.210135
4	20	9	280	0.5769	4.777989
5	40	6	270	0.6605	3.602544
6	40	7	265	0.6851	3.284921
7	40	8	280	0.5491	5.206971
8	40	9	275	0.5768	4.779495
9	60	6	275	0.5160	5.747006
10	60	7	280	0.5215	5.654914
11	60	8	265	0.7221	2.828053
12	60	9	270	0.7352	2.67189
13	80	6	280	0.4996	6.027551
14	80	7	275	0.6531	3.700406
15	80	8	270	0.6836	3.303959
16	80	9	265	0.8944	0.969364
					$\sum$ 67.039091
					$\bar{\bar{T}}$ 4.189943

Fig. 2 shows the S/N ratio respond graph for fill time. The total fill time was around the desired (the smaller the better) value. However, the relative importance amongst the parameters for total fill time still needed to be known so that optimal combinations of the parameter levels can be determined more accurately. Plotted results had determined the optimum parameters for producing an optimum fill time to be A1, B1 and C4 of mould temperature 20 °C, runner size 6 mm and melting temperature 280 °C respectively.

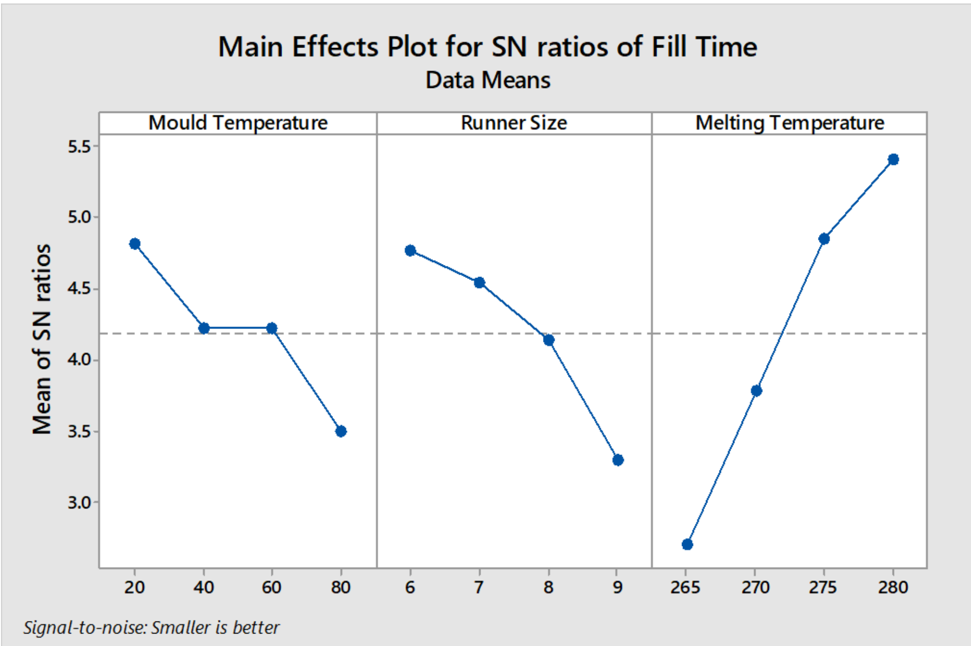

Fig. 2: S/N Respond Graph for Fill Time

Analysis of Variance (ANOVA)

ANOVA was conducted on the fill time test results as shown in Table VI. ANOVA indicate the error, e* collected from the significant factor that is calculated and the error, e, was identified with or without zero. If the error is zero and all factors were significant, as a result, the confidence interval for optimal performance cannot be determined because of the error variance should be determined in advance.

Further, from this analysis, the data collected from the analysis of variance (ANOVA) show the variance ratio, F for the melting temperature, C gives the largest contribution of 51.62% for the fill time,

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followed by the runner size, B with the percent contribution of 12.76%. Mould temperature gives the lowest percentage contribution of 8.21%. Therefore, during the injection process on the quality of fill time, both of these parameters must be emphasized. Theoretically, melting temperature of the parison product using PET material affects the fill time. In addition, the cooling rate should be emphasized because it affects the production of the parison in the injection process. From the variance ratio, the analysis can be extended to find the confidence level. The confidence interval indicates the percentage of quality of the product. The percentage of confidence level ranges from 90% to 99%.

The higher the confidence interval, the better the variable contribution to the quality of the products. From the analysis of variance, the confidence interval can be determined using the F-Table. The comparison was done by identifying the variance ratio and compared the DOF for f1 and f2. Therefore, the highest confidence interval is the melting temperature, C which gives the confidence level of 99% and runner size, B gives a confidence level of 90%. This study shows that mold temperature, A provides a small percentage of contribution in determining the fill time of injection process of the parison which is 8.21%. The value of the variance ratio for mold temperature shows that the confidence is at a level below 90% ($\alpha = 0.1$). This means that factor A does not affect the fill time of parison during the injection process. Although these factors do not affect the fill time, these factors may affect the determination of the injection process optimization.

Table VI: Analysis of Variance (ANOVA) for Total Fill Time

Factor	Parameter	DOF, fn	Sum of Square, S	Variance, V	Variance Ratio, F	Pure Sum (S')	Percent Contribution P (%)
A	Moulding Temperature	3	0.02301	0.00767	2.4977	0.0138	8.21
B	Runner Size	3	0.03065	0.01022	3.3265	0.0214	12.76
C	Melting Temperature	3	0.09594	0.03198	10.4133	0.0867	51.62
All other/ Error		6	0.01843	0.00307			27.42
Total		15	0.16803				100.00

Confidence Interval and Optimum Range

Table VII indicates the optimum S/N ratio, confidence interval, and optimum performance ranges for fill time. From the ANOVA analysis, factors B and C have influences on the fill time which the optimum factors can be used to produce high-quality parisons. The confidence interval is at confidence level of 99% ($\alpha = 0.01$). The factors that affect the change in fill time are runner size (B1) and melting temperature (C4). The optimum performance is 6.00 dB and performance range that will contribute to the verification experiment for fill time is in the range of 4.1024 dB to 4.2756 dB.

Table VII: S/N Ratio Optimum, Confidence Interval and Optimum Performance Range for Fill Time

Optimal Levels of Verification: B1C4

Optimum parameter calculation:

$$\overline{T} + (\overline{B1} - \overline{T}) + (\overline{C4} - \overline{T})$$

$$4.1899 + (4.7730 - 4.1899) + (5.4169 - 4.1899) = 6.00 \text{ dB}$$

Overall Performance	:	4.189
Confidence Interval at confidence level 99% ($\alpha = 0.01$)	:	± 0.08665
Optimum Performance Range	:	$4.1024 < \mu < 4.2756$

IV. CONCLUSION

Overall process optimization for the injection process parameters has been done via Taguchi method in order to produce good quality parison. Justification of the decision for the optimization process had been done through simulation analysis verification. Overall, the melting temperature (A) is the most important factor in producing good quality parison for a plastic bottle. This outcome was verified by ANOVA obtained from the fill time performance characteristics. The ANOVA results showed the melting temperature (A) gives the percentage of contributions for all types of single performance even though the percentage of donations and the level of confidence in the performance of the studied differ from one another. It was found that the optimization result for the individual respond on fill time was A1B1C4 for the injection process for 8 cavities mold for 20g parison.

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