Penerbit Akademia Baru

Journal of Advanced Research in Applied Mechanics
ISSN (online): 2289-7895 | Vol. 10, No. 1. Pages 1-8, 2015

An Optimization of Shrinkage in Injection Molding Parts by Using Taguchi Method

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Abstract – *This research paper is about an optimization of shrinkage in injection molding part by using the Taguchi Method. The part chosen was from a company which had a critical issue of shrinkage on one of the parts produced. The approach of Taguchi method is applied for the optimization of selected process parameters such as the mold temperature, melt temperature, packing pressure, packing time, and cooling time. For this purpose, Moldflow Plastic Insight (MPI) software was used for the simulation of injection molding process. The number of simulation was based on the three levels of* L_{27} *Taguchi Orthogonal Array (OA). The Minitab software was used to analyze the result where the S/N (signal-to-noise) ratio and analysis of variance (ANOVA) were utilized to see the most significant factors contributing to shrinkage. The confirmation test shows the best combination of process parameters using the Taguchi approach to minimize the shrinkage on the part.*

Keywords: Plastic Injection molding, Taguchi method, Shrinkage

1.0 INTRODUCTION

Injection molding is a fantastic process because of its capability of economically in making extremely complete parts [1-3]. Shrinkage is the most common problem that occurs in the injection molding plastic parts [4]. The difficulty in setting the optimal parameter to run the injection molding process has led to the shrinkage problem. Some of shrinkage problems are influenced by wall thickness and mold surface temperature [5]. The shrinkage problem needs to be predicted first as soon as before the manufacturing process starts. Based on the literature review [2-9], it was stated that the significant parameter effects on shrinkage are melt temperature, packing time, mold temperature followed by packing pressure as the insignificant factor. These four parameters really contribute to the shrinkage problem in injection molding. There are several tools and techniques of optimization, however, this paper focuses only on Taguchi Method. Previous researches, [2-4], [7-8], and [10-16], have applied the Taguchi method for optimization of parameter in injection molding.

2.0 METHODOLOGY

The steps involved in the project begin with data collection from the company and end with the confirmation test as shown in Figure 1.

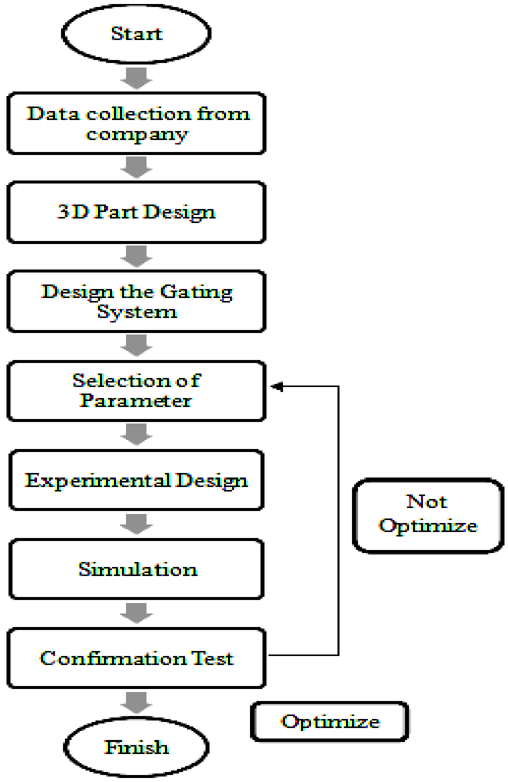

Figure 1: Steps involved in the methodology.

2.1 3-D Design of the Product

The injection molding part was designed using the CAD software. It was designed to its dimension according to the part drawing dimension data provided by the company. It has the length of 329.4mm, width of 31.7mm, height of 45.98mm and thickness of 2mm. Figure 2 shows the 3D drawing of the part.

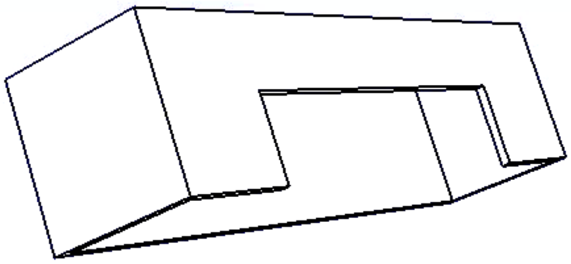

Figure 2: Design of product**.**

2.2 Gating System Design

Moldflow Plastic Insight (MPI) software was used to design the gating system of the part. It is also used to simulate the injection molding process where the flow of material to become the part can be seen. The specification for the gate is 7mm for the runner size diameter, sprue size diameter of 4mm and gate size of 2.5mm x 2.7mm.

2.3 Selection of Parameters

Parameters decided to be studied on the part are the melt temperature (A), mold temperature (B), packing pressure(C), packing time (D) and cooling time (E). By referring to the literature review, these are the significant parameters in the injection molding process. Table 1 shows the selected parameters in three experimental levels.

Table 1: The process parameters and their levels

Experimental Factors	Experimental Level		
	1	2	3
A: Melt Temperature (^{0}C)	220	240	260
B: Mold Temperature (^{0}C)	50	60	70
C: Packing Pressure (MPa)	45	70	85
D: Packing Time (Sec)	2	2.5	2.8
E: Cooling Time (Sec)	50	55	60

2.4 Experimental Design

Taguchi method was chosen as the tool of the experimental design in this study. It involves the optimization of the controllable and uncontrollable factors. The controllable factors in this project were the five parameters chosen, which are the melt temperature (A), mold temperature (B), packing pressure (C), packing time (D) and cooling time (E), while the uncontrollable factors also known as the noise factors are the factors that hard to be controlled. In this project, ambient temperature was chosen as the noise factor.

By using the Minitab software, the suitable Orthogonal Array was L_{27} with five factors that were the parameters with three experimental levels. The S/N ratio of "the smaller the better" was chosen since the experiment was to minimize the shrinkage. It is used to identify the most robust set of parameter after getting the result. A statically analysis of variance (ANOVA) was also utilized to present the influence of process parameter.

The value of the S/N ratio was calculated by using equation (1) and the Mean Square Deviation (MSD) as in Equation (2). The symbol of ***y*** represents both values of the studied result that is the shrinkage while ***n*** indicates the number of tests in a trial which is three throughout the whole experiment.

$$S/N \ ratio = -10 \log MSD \tag{1}$$

$$MSD = \frac{1}{n}\sum_{i=1}^{n} yi^2 \tag{2}$$

3.0 RESULTS AND DISCUSSION

Based on the selected parameter, the OA was built using the Minitab software. The trial experiments were running using the parameters given. The result was as follows in Table 2:

Table 2: Shrinkage Result.

Trial No.	**Parameters**					**Ambient Temperature (°C)**		
						25	30	35
						Analyze Result		
	Melt Temp. (A)	Mold Temp. (B)	Packing Pressure (C)	Packing Time (D)	Cooling Time (E)	A1	A2	A3
1	220	58	45	2.0	50	9.040	8.855	8.669
2	220	58	45	2.0	55	9.047	8.853	8.680
3	220	58	45	2.0	60	9.035	8.852	8.683
4	220	60	70	2.5	50	9.029	8.854	8.671
5	220	60	70	2.5	55	9.034	8.834	8.668
6	220	60	70	2.5	60	9.075	8.856	8.669
7	220	70	85	2.8	50	9.090	8.858	8.673
8	220	70	85	2.8	55	9.086	8.867	8.677
9	220	70	85	2.8	60	9.097	8.845	8.669
10	240	58	70	2.8	50	10.020	9.836	9.653
11	240	58	70	2.8	55	10.075	9.797	9.645
12	240	58	70	2.8	60	10.146	9.800	9.649
13	240	60	85	2.0	50	10.375	9.833	9.556
14	240	60	85	2.0	55	10.456	9.793	9.476
15	240	60	85	2.0	60	10.583	9.863	9.597
16	240	70	45	2.5	50	10.657	9.844	9.661
17	240	70	45	2.5	55	10.724	9.964	9.975
18	240	70	45	2.5	60	10.889	10.532	10.489
19	260	58	85	2.5	50	10.970	10.780	10.623
20	260	58	85	2.5	55	10.963	10.820	10.579
21	260	58	85	2.5	60	9.950	10.832	10.687
22	260	60	45	2.8	50	10.945	10.790	10.610
23	260	60	45	2.8	55	10.954	10.832	10.596
24	260	60	45	2.8	60	10.963	10.850	10.622
25	260	70	70	2.0	50	10.968	10.876	10.636
26	260	70	70	2.0	55	11.320	11.245	11.123
27	260	70	70	2.0	60	11.789	11.546	11.443

3.1 Analysis Result - S/N Ratio Analysis

The analysis result of shrinkage from Table 2 was presented into a form of response table of S/N ratio as in Table 3. From this table, the most optimum parameter for minimizing the shrinkage defects can easily be noticed.

Table 3: Response S/N table for Shrinkage.

Factor Level	**Melt Temp.(A)**	**Mold Temp.(B)**	**Packing Pressure (C)**	**Packing Time(D)**	**Cooling Time(E)**
1	8.862	9.798	9.986	10.007	9.866
2	10.033	9.866	9.972	9.949	9.929
3	10.900	10.131	9.837	9.839	10.000
Delta	2.039	0.333	0.149	0.168	0.135
Rank	1	2	4	3	5

Table 4 summarizes the whole result of S/N ratio for shrinkage. The optimal level was selected based on the highest point in Figure 3. The rank shows which factor affects shrinkage the most starting with melt temperature (A) in the first rank and the least affecting factor that is the cooling time (E).

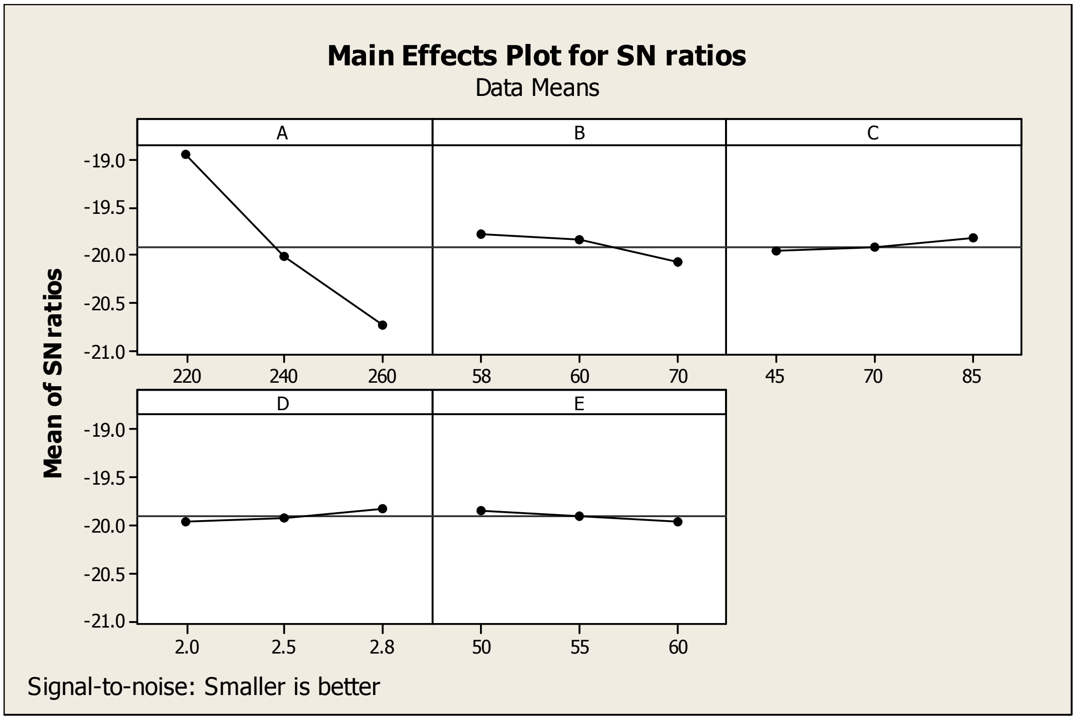

Figure 3: Response S/N diagram for Shrinkage.

Table 4: Optimum Setting for Shrinkage.

Factor	Melt Temp.(A)	Mold Temp.(B)	Packing Pressure (C)	Packing Time(D)	Cooling Time(E)
Optimum Level	1	1	3	3	1
Rank	1	2	4	3	5

3.2 Analysis result – Analysis of Variance (ANOVA)

By referring to the F-distribution statistic table, the $F_{0.05,2,26} = 3.37$ for a level of significant factor equals to 0.05 (or 95% confidence level). Melt temperature (A) [Fstatistic = 404.96 > 3.37], and mold temperature (B) [Fstatistic = 10.40 > 3.37] show that both factors are significant to the shrinkage defects. For packing pressure (C) [Fstatistic = 2.13 < 3.37], packing time (D) [Fstatistic = 2.41 < 3.37], and cooling time (E) [Fstatistic = 1.48 < 3.37], these three factors are not significant to the shrinkage defects. From this, it indicates the significant and insignificant factors to shrinkage.

From Table 5, the melt temperature (A) contributes the most percentage values which is 96.1% followed by mold temperature (B) with 2.47 %. The factor of packing time (D) only gives 0.57%, followed by packing pressure (C) with 0.51% and lastly the cooling time (E) which contributes the least to the shrinkage with 0.35%.

Table 5: ANOVA for Shrinkage.

Source of Variance(Factors)	Degree of Freedom(*f*)	Sum of Square(*SS*)	Mean Square(*MS*)	F-statistic(*F*)	Percentage (%)
Melt Temp.(A)	2	14.6986	7.3493	404.96	96.10
Mold Temp.(B)	2	0.3774	0.18869	10.40	2.47
Packing Pressure(C)	2	0.0772	0.03862	2.13	0.51
Packing Time(D)	2	0.0875	0.04374	2.41	0.57
Cooling Time(E)	2	0.0538	0.02689	1.48	0.35
Residual Error	16	0.2904	0.01815	0.00	
Total	26	15.5848	7.66539	421.38	

3.3 Confirmation Test

After getting all the results, the confirmation test needs to be run to see whether the optimized result can be used to reduce the shrinkage defect. This is to make sure that the objectives of the project were achieved.

Table 6: Confirmation test result for shrinkage.

							Ambient Temperature (°C)		
							25	30	35
		Recommended Parameters setting					Analyze Result		
	Trial	(A)	(B)	(C)	(D)	(E)	A1	A2	A3
1	Optimum Level	1	1	3	3	1	7.803	7.708	7.521
	Parameter Setting	220°C	58°C	85MPa	2.8sec	50sec			
		Mean of analyze result for shrinkage						7.68%	
		Prediction shrinkage by Minitab						8.18%	

The recommended parameter setting of shrinkage was produced from the combination of optimum level of A1, B1, C3, D3, and E1. It is from the parameter setting of melt temperature with 220°C, mold temperature of 58°C, packing pressure of 85MPa, packing time of 2.8 second and cooling time of 50 second as shown in Table 6.

After running the confirmation test, the result was again analyzed and compared with Minitab. This is to evaluate whether the optimum setting of parameters predicted was in the allowable range. Upon that, the margin error from the prediction and simulation results was set below than 10%. The margin error was calculated by using the equation below:

$$\textit{Margin Error}\ (\%) = \frac{\textit{Confirmation test} - \textit{Predicted}}{\textit{Predicted}} \times 100$$

From the result, it can be concluded that for both responses, the margin error is below 10%. This means that the confirmation test is accepted since it has minimized the defects for shrinkage.

Table 7: Comparison Test Result

Response	Prediction (Minitab)	Simulation (Confirmation Test)	Error Margin (%)
Shrinkage	7.68%	8.18%	6.15%

4.0 CONCLUSSION

From this study, it can be concluded that Taguchi method could be used to minimize the shrinkage defects. It is a very useful method that can be used to provide efficient and economical ways instead of trial and error methods which contribute to waste. The conclusions of the project are as follows:

i. The recommended setting of parameters for shrinkage was produced by the combination of A1, B1, C3, D3, and E1. That was the setting of melt temperature with 220°C, mold temperature with 58°C, packing pressure of 85MPa, packing time of 2.8seconds, and cooling time of 50seconds. From the ANOVA table, it shows that the melt temperature (A) contributes the most percentage values which is 96.1% followed by mold temperature (B) with 2.47 %. The factor of packing time (D) only gives 0.57%, followed by packing pressure(C) with 0.51% and lastly the cooling time (E) which contributes the least to the shrinkage with 0.35%.

ii. The margin error was small which is below 10%. This concludes that the confirmation test was accepted. The recommended parameter setting reduced the shrinkage defects on the part in this study.

iii. From the result of shrinkage, response shows that the least contributing factors were caused by the cooling time. This might be due to the small difference between the cooling times set for every level which only differs by 5 seconds from one another.

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