IOP Conference Series: Materials Science and Engineering

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To cite this article: H Radhwan *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **551** 012027

IOP Conf. Series: Materials Science and Engineering **551** (2019) 012027 doi:10.1088/1757-899X/551/1/012027

Optimization Parameters to Reduce the Warpage Defect of Plastic Injection Molding Process for A Thin-Shell Part Using Design of Experiment

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Abstract. Development of light, small and thin plastic products that possess high strength characteristic such as electronic devices have become one of the tremendous demands in the plastic injection molding industry nowadays. However, smaller and thinner wall part design has increased the possibility for the parts to warp. The aim of this study is therefore to determine the best set combination of molding parameters that could reduce the warpage defect. There are six parameters that have been selected in this study which are mold temperature, melt temperature, packing time, cooling time, injection time and packing pressure. Taguchi orthogonal array is used to simplify the experimental runs. The analysis is done by applying S/N ratio approach and ANOVA method. Based on the results obtained from the analysis, it is found that the best set combination parameters give out the smallest warpage value.

1. Introduction

Nowadays, the development of plastic products as consumer products such as communication and electronic devices like mobile telephones, portable computers, and etc. has made these products to be small, thin and light. Smallest and thinnest plastic parts mean the possibility of parts to warp will definitely increase. In plastic injection molding, the production of thin walled parts is exceptionally troublesome due to the fact that melted plastic cannot fill the mold cavity easily [1-3]. In order to optimize the performance of the plastic injection molding process, the best parameter setting is very important. Therefore, this study will be using parameter design in Taguchi method to find the optimal injection molding processing conditions for improving the quality characteristics of the plastic part produced or to be more specicific; this method will be employed to facilitate the experimental design for warpage reduction analysis [2, 4]. There are various tools and technique of optimization to produce

IOP Conf. Series: Materials Science and Engineering **551** (2019) 012027 doi:10.1088/1757-899X/551/1/012027

an optimized setting for plastic production such as Response Surface Methodology (RSM), Taguchi and so on [5-9]. In this study, Design of experiment is used to conduct the optimization process. DOE is the most powerful quality improvement technique to reduce process variation, enhances process effectiveness and process capability [4]. DOE of Taguchi orthogonal array, S/N ratios, and ANOVA was used to exploit the effects of process parameters the selected thin shell part, and they have been used throughout this study in both simulation and analysis [2]. Six parameters which comprise of mold temperature, melt temperature, packing time, cooling time, injection time and packing pressure were used as model variables. Taguchi has been used by researchers [2, 4, 10-14] respectively as an optimization method to improve defects problem specifically warpage defect, and this technique gives a proficient way to optimize the quality characteristics and cost in the manufacturing process. Tang. S. H et al. [12] in his study found out that the melt temperature as the most significant factor affecting warpage. Meanwhile, B. Ozcelik and T. Erzurumlu [15] in their study on the effects of injection molding parameter in warpage identified that the most influential parameter on warpage on thin shell PC/ABS material was packing pressure. The same parameter, which is the packing pressure had also become the most significant factor contributing to warpage based on Taguchi optimization technique applied by Oktem.H et al.[14], Huang and Tai [13] and Liao et al. [16].

2. Methodology

The steps involved in the project begin with the 3D Modelling until confirmation run. It was shown in table 1.

Table 1. Steps involved in the methodology

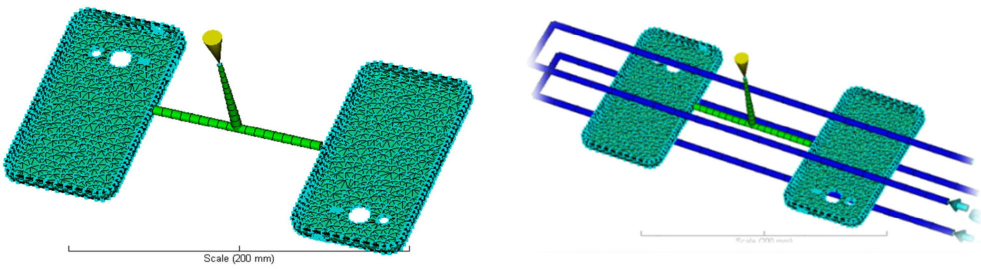
3D Modelling	• Drawing the selected part by using CATIA
Gating System Design	• Defining gate location/size, runner size and cooling channel
Parameters and respective levels selection	• Applying Minitab software
Experimental Design	• Applying Taguchi Orthogonal Array
Experimental Implementation	• Simulation analysis using Moldflow software
Interpreted data and Optimization	• Applying Taguchi method and ANOVA
Confirmation run	• Compare predicted value with confirmation value

2.1 3D Modelling

For the analysis, a cellular phone cover was chosen to be the model of study. It was designed with CATIA V5R16. The part's dimensions which consider its length, width, height, and thickness are 130, 70, 11 and 1 mm respectively. The model that has been drawn by using CATIA V5R16.

2.2 Gating System Design

The number and location of the gates need to be determined. The best gate location should be placed where the user cannot see the gate marks after assembling the products. Figure 1(a) shows the gating system design for the part study, cellular phone housing. In this study, the gate type chosen was the side gate with a two-plate mold. The dimension for the runner's system is the circular size with 6 mm, 6.5 mm and 8 mm. Figure 1(b) shows the part meshing with dual domain and cooling channel for a thin shallow plate. Based on the meshing, the thin shallow parts are divided into 9576 surface triangle elements. The proper cooling system was designed to assist the whole mold system, and the diameter for each channel is 6 mm, and the space in between channel is 45 mm.



a) Gating system design. b) Part meshing and cooling channel

Figure 1. Gating system design.

2.3 Selection of Parameters

Based on previous researchers, there are several parameters that are significant to be optimized for better performance of plastic model upon warpage defect. In this study, the parameters selected to be optimized are mold temperature, melt temperature, packing time, cooling time, injection time and packing pressure. Table 2 shows the selected parameters used in this study and their respective level. The value for each level is determined based on the recommended process setting upon the selection of material in Moldflow software.

Table 2. The process parameters and their levels.

Experimental Factors	Experimental Level		
	1	2	3
A: Mold Temperature (°C)	70	90	120
B: Melt Temperature (°C)	300	320	340
C: Packing time (Sec)	8	10	12
D: Cooling time (Sec)	8	10	12
E: Injection time (sec)	0.5	0.8	1
F: Packing pressure (MPa)	120	140	170

2.4 Experimental Design

The experimental design is done by using the Taguchi method. There are six parameters selected to control the injection process: mold temperature (A), melt temperature (B), packing time (C), cooling time (D), injection time (E) and packing pressure (F). Every factor consists of three levels each where a Taguchi orthogonal array L27 (3^6) was used to suit the inputs. Taguchi Orthogonal Array Variance for L27 (3^6) generated by Minitab.

3. Results and Discussions

3.1 Taguchi Analysis Result

S/N (signal-to-noise) ratio is one of the measurement indexes to find the optimal process values for improving quality characteristics. Data points were analyzed using the “smaller-the-better” approach since this research is focused on minimizing the warpage in the injection molding process within optimal process parameters. The S/N ratio was calculated using equations (1) and MSD using equation (2). MSD is the mean square deviation, where y represents the value of result and n is the number of tests in one trial [17].

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

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

Minitab software has been used in this study to analyze the results obtained from the Moldflow simulation, in order to identify the best parameter to be optimized. The warpage results obtained in the simulation process were then used to be analyzed in Minitab to get the S/N ratio, mean and standard deviation values. The result is summarized and tabulated in table 3. Table 4 shows the response table for the signal to noise ratios which presented the best set of combination parameters and it is determined by selecting the highest level value for each factor. It shows here that the optimal process parameters are A(3), B(1), C(3), D(3), E(2) and F(3) for PC/ ABS material. Besides, this table also ranks every factor used based on the highest delta. From this S/N ratios response table, melt temperature (B) has become the first rank, followed by mold temperature (A), cooling time (D), packing time (C), packing pressure (F) and injection time (E) seems to fall on the last rank. Hence, it can be concluded that melt temperature is the most effective factor to reduce the warpage while injection time has become the insignificant one in this study. Based on the table, the recommended setting result of warpage was produced by a combination of A3, B1, C3, D3, E2, F3 and each one represents mold temperature 120 □C, melt temperature 300 □C, packing time 12 seconds, cooling time 12 seconds, injection time 0.8 seconds, and packing pressure 170 MPa.

Table 3. Summary of result

Run	Result Of Analysis		Mean	Msd	S/N Ratio
	27	30			
1	0.7945	0.7730	0.78375	0.01520	2.11563
2	0.7916	0.7727	0.78215	0.01336	2.13357
3	0.7947	0.7759	0.78530	0.01329	2.09867
4	0.8391	0.8244	0.83175	0.01039	1.59980
5	0.8355	0.8216	0.82855	0.00983	1.63332
6	0.8392	0.8149	0.82705	0.01718	1.64843
7	0.8692	0.8520	0.86060	0.01216	1.30354
8	0.8707	0.8482	0.85945	0.01591	1.31484
9	0.8605	0.8407	0.85060	0.01400	1.40490
10	0.7903	0.6926	0.70095	0.01181	3.08564
11	0.7121	0.6937	0.70290	0.01301	3.06139
12	0.7131	0.6946	0.70385	0.01308	3.04965
13	0.7649	0.7471	0.75600	0.01259	2.42896
14	0.7689	0.7511	0.76000	0.01259	2.38313
15	0.7682	0.7483	0.75825	0.01407	2.40300
16	0.8472	0.8270	0.83710	0.01428	1.54382
17	0.8352	0.8151	0.82515	0.01421	1.66870
18	0.8608	0.8412	0.85100	0.01386	1.40083
19	0.7111	0.6928	0.70195	0.01294	3.07314
20	0.712	0.6937	0.70285	0.01294	3.06201
21	0.7129	0.6944	0.70365	0.01308	3.05212
22	0.7279	0.7115	0.71970	0.01160	2.85641
23	0.7182	0.7017	0.70995	0.01167	2.97486
24	0.7207	0.7043	0.71250	0.01160	2.94373
25	0.7857	0.7682	0.77695	0.01237	2.19159
26	0.8045	0.7831	0.79380	0.01513	2.00499
27	0.7932	0.7746	0.78390	0.01315	2.11418
		TOTAL	20.9097	0.34274	60.5509
		MEAN	0.77443	0.01269	2.24262

Table 4. Response table for signal to noise ratio.

Level	A	B	C	D	E	F
1	1.695	2.748	2.193	2.208	2.244	2.213
2	2.336	2.319	2.265	2.076	2.249	2.250
3	2.697	1.661	2.270	2.444	2.235	2.265
Delta	1.002	1.087	0.077	0.368	0.013	0.052
Rank	2	1	4	3	6	5

3.2 Analysis of Variance (ANOVA)

From ANOVA result in table 5 below, the F0.05,2,26 =3.37 for a level of significant parameter with 95% confident interval that is equal to 0.05. Therefore, Injection time (E) [Fstatistics = 0.10 < F 0.05,2,26 = 3.37], and Packing pressure (F) [Fstatistics = 1.61 < F 0.05,2,26 = 3.37] does not give a significant effect to the warpage as their F-statistic values are lower than 3.37. While mold temperature (A) [Fstatistics = 569.13 > F 0.05,2,26 = 3.37], melt temperature (B) [Fstatistics = 662.28 > F 0.05,2,26 = 3.37], packing time (C) [Fstatistics = 4.10 > F 0.05,2,26 = 3.37], and cooling time (D) [Fstatistics =76.77 > F 0.05,2,26 = 3.37], give a significant effect to the warpage, with mold temperature (B) giving the highest significant level. The melt temperature (B) contributes the highest percentage value which is 50.4% followed by mold temperature (A) 43.31%, and cooling time (D) 5.84%, as the most influence factor for warpage defect. Meanwhile packing time (C) contributed 0.31%, packing pressure (F) contributed 0.12% and lastly injection time (E) only contributed 0.14% and thus, it make the packing time, packing pressure and injection time to be the least significant factors for the warpage defect in this study.

Table 5. ANOVA table

Source	f	SS	MS	F-Statistic	Percentage
A	2	4.63835	2.31918	569.13	43.31%
B	2	5.39749	2.69875	662.28	50.4%
C	2	0.03344	0.01672	4.10	0.31%
D	2	0.62570	0.31285	76.77	5.84%
E	2	0.00085	0.00043	0.10	0.0076%
F	2	0.01312	0.00656	1.61	0.12%
Error	14	0.05705	0.00656		
Total	26				

3.3 Confirmation Test

The confirmation runs were conducted to measure the reliability of optimization solutions obtained from the software analysis. The comparison of test results between the theoretical prediction and the confirmation test results was the final consideration that will evaluate whether the optimum parameters predicted were in the allowable range as shown in table 6. The margin of error from the prediction and simulation results was set below than 10%. Margin error was calculated using the equation (3) below:

$$\text{Margin Error} = \frac{(\text{Confirmation test} - \text{Predicted})}{\text{Predicted}} \times 100 \qquad (3)$$

Table 6. Comparison Test Result.

Response	Prediction (Minitab)	Simulation (Confirmation Test)	Error Margin (%)
Warpage	0.667937	0.69205	3%

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.

4. Conclusions

Based on the results obtained from the analysis, it is found that the best set combination parameters to be used are: mold temperature (A) of 120 ^{o}C, melt temperature (B) of 300 ^{o}C, packing time (C) of 12 s, cooling time (D) of 12 s, injection time (E) of 0.8 s and packing pressure (F) of 170 MPa. These optimum combination parameters successfully reduce the warpage value to 0.6922 mm for ambient temperature 27◦C and 0.6919 mm for ambient temperature 30 ^{o}C. By calculation, these results give the margin error as low as 3% when compared to the predicted value, and hence it can be said that the predicted result is accepted and reliable. According to ANOVA result, with a 95% confidence interval, it is concluded that the significant parameters that affect warpage are melt temperature, mold temperature and packing time. Meanwhile, injection time and cooling time give the least percentage that contributes to warpage defect. Among all factors, melt temperature has become the most significant factor and injection time is the least factor that affecting the warpage of the thin shell part in this study.

Acknowledgments

We specially thank the reviewer(s) for their useful advice and comments. The authors acknowledge the School of Manufacturing Engineering, Universiti Malaysia Perlis for the lab facilities. Special thanks to those who contributed to this project directly or indirectly.

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