International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:10, No:12, 2016

The Analysis of Defects Prediction in Injection Molding

Mehdi Moayyedian, Kazem Abhary, Romeo Marian

Abstract**—**This paper presents an evaluation of a plastic defect in injection molding before it occurs in the process; it is known as the short shot defect. The evaluation of different parameters which affect the possibility of short shot defect is the aim of this paper. The analysis of short shot possibility is conducted via SolidWorks Plastics and Taguchi method to determine the most significant parameters. Finite Element Method (FEM) is employed to analyze two circular flat polypropylene plates of 1 mm thickness. Filling time, part cooling time, pressure holding time, melt temperature and gate type are chosen as process and geometric parameters, respectively. A methodology is presented herein to predict the possibility of the short-shot occurrence. The analysis determined melt temperature is the most influential parameter affecting the possibility of short shot defect with a contribution of 74.25%, and filling time with a contribution of 22%, followed by gate type with a contribution of 3.69%. It was also determined the optimum level of each parameter leading to a reduction in the possibility of short shot are gate type at level 1, filling time at level 3 and melt temperature at level 3. Finally, the most significant parameters affecting the possibility of short shot were determined to be melt temperature, filling time, and gate type.

Keywords**—**Injection molding, plastic defects, short shot, Taguchi method.

I. Introduction

THE most significant process for manufacturing plastics is injection molding. Injection molding is considered for mass production of the complex geometry of plastic products, which require accurate dimensions [1]. One of the key points of this industry is the advantages such as short product cycles, good mechanical properties, low cost, and being light weight [2]. The final quality of an injected part is related to different factors which are *part design, mold design, material and process parameters* [3]-[5]. The injection molding process is unstable repeated work, consisting of filling, packing and cooling phases. During the filling stage, a hot polymer melts quickly to fill the cold cavity. During the packing stage, the pressure of molten plastic for injection is increased to ensure that the cavity is filled properly. Finally, during the cooling stage, the molten plastic cools down and solidifies adequately so that the final product is stable for ejection from the cavity [6]-[9].

Different factors cause different defects of the products like warpage, weld line and sink mark during the manufacturing process, but short shot causes the most significant defects of plastic parts. The evaluation of short shot in injection molding is very complicated [2], [10], [11]. When insufficient material was injected into the mold and cannot fill the cavity, short shot will happen [12]. It is caused by different factors such as wrong plastic material selection, inaccurate processing parameters, incorrect mold design, and part design. Hence, because of the complexity of the melt flow process, it is critically significant to have control over the factors of influence during the injection molding process [10], [13]

In this paper, different processes and geometric parameters for reducing the possibility of short shot defect in injection molding are evaluated. To make sure that other factors such as the size of runner and the gate system do not affect the simulation result, the selection of the right size for the runner and gate system is conducted via simulation. A new definition for short shot analysis is proposed which is considered via simulation for 18 trial numbers.

II. Methodology

Among four essential factors, namely mold design, part design, material, and process parameters, *process parameters and mold design* are clearly the essential factors which lead to different defects in injection molding, and therefore, they are selected herein for the analysis of short shot possibility. Materials and part design are ignored simply because it is not possible to do research on the application of all plastic materials (more than 17,000 in the world) in injection molding and consider all customer requirements [14].

With advancements in Computer Aided Engineering (CAE) technology, simulation of the injection molding process is now an influential tool to support engineers, and meets these challenges as a replacement for conventional methods. In this paper, the CAE technique and Taguchi method are jointly employed to examine the impact of different parameters on the short shot index of injected parts to reduce its short shot. Also, orthogonal array experiment of L18 is selected to find the optimum levels of process conditions and geometric parameters and evaluate their significance in reducing the possibility of short shot for two thin shell plastic samples via the Signal to Noise ratio (S/N) and Analysis Of Variance (ANOVA).

A. Selection of Factor Levels

There are three levels of the selected factors, each of which is considered using the Taguchi method. The reason for selecting three levels (low, medium, high), instead of two levels (low, high), is due to the fact that three levels of each

Mehdi Moayyedian is with the University of South Australia, School of Engineering, Mawson Lakes Campus, SA 5095, Australia (phone: +61883025561, e-mail: mehdi.moayyedian@unisa.edu.au).
Kazem Abhary and Romeo Marian are with the University of South Australia, School of Engineering, Mawson Lakes Campus, SA 5095, Australia.

factor give more accurate results in comparison to two levels. Different levels of selected parameters are shown in Table I.

TABLE I
THREE LEVELS OF SELECTED PARAMETERS

parameters	Level 1	Level 2	Level 3
Gate type, A	1	2	-
Filling time, B (s)	0.2	0.6	1
Part cooling time, C (s)	3	3.9	5
Pressure holding time, D (s)	1	2	3
Melt temperature, E (°C)	200	230	280

B. Selection of Orthogonal Array

According to the number of parameters and levels which have been chosen, L18 orthogonal array is selected, as shown in Table II.

TABLE II
L18 ORTHOGONAL ARRAY

Experiment	A	B	C	D	E
1	1	1	1	1	1
2	1	1	2	2	2
3	1	1	3	3	3
4	1	2	1	1	2
5	1	2	2	2	3
6	1	2	3	3	1
7	1	3	1	2	1
8	1	3	2	3	2
9	1	3	3	1	3
10	2	1	1	3	3
11	2	1	2	1	1
12	2	1	3	2	2
13	2	2	1	2	3
14	2	2	2	3	1
15	2	2	3	1	2
16	2	3	1	3	2
17	2	3	2	1	3
18	2	3	3	2	1

III. SIMULATION MODELING

After designing two circular parts as two samples for this application, the next step is to simulate the selected parts via SolidWorks plastic. For simulation, defining the right injection system is necessary. Hence, designing the sprue, runner and gate system based on two circular parts with 100 mm diameter and 1mm thickness should be considered as shown in Fig. 1. The reason for having two round parts with the thickness of 1 mm is to eliminate short shot defect in a critical condition. Also, as mentioned before, one of the selected parameters for this study is the gate type. Finally, the round gate and the modified edge gate were evaluated via SolidWorks Plastics and experiments [15], [16].

In order for the results to be accurate, finite element analysis is applied to the solid models via triangular finite elements, as shown in Fig. 2. The selected material for injection is polypropylene (P.P). Different sizes have been evaluated for the shell mesh and injection system. Finally, a triangle size of 1 mm is selected for the shell mesh of the injected part and for the injection system which includes sprue, runner and gate, and smaller mesh size was applied. Hence, the triangle size is 0.3 mm for the sprue and runner and triangle 0.2 mm for the gate was selected.

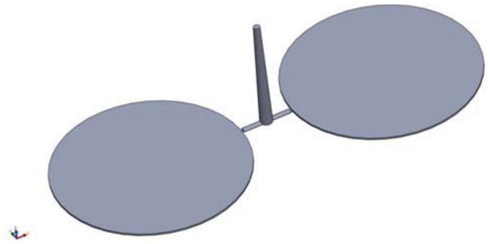

Fig. 1-3D design of plastic part with sprue, runner and gate system

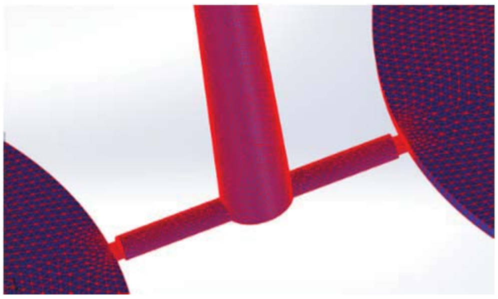

Fig. 2 Finite element analyses for 3D part design

The proposed method is to calculate the short shot possibility which equals the ratio of simulated inlet pressure to maximum inlet pressure for a specific injection machine as shown in (1). The maximum injection pressure for the selected injection machine is 100 MPa. By increasing the ratio, the possibility of short shot defect increases; hence, the smaller the ratio, the better the objective of this study. The calculated results for short shot defect and the S/N ratio have been determined and tabulated in Table III.

$$possibility\ of\ short\ shot = \frac{Simulated\ inlet\ pressure}{Maximum\ inlet\ pressure} \quad (1)$$

From the data in Table III, the average S/N ratio for the response table can be calculated as shown in Table IV. Also, Fig. 3 is plotted using the S/N response in Table IV for the possibility of short shot to determine the optimal levels of four process parameters and one geometric parameter. Eighteen trials of simulation were taken into account and the results presented in Table IV. The response table of S/N ratio and S/N diagram in Table IV and Fig. 3 were created, respectively.

From the S/N response Table IV, it can be inferred that the larger the value of ΔT, the more is the significance of each parameter in affecting short shot defect. Based on Table IV, the selected parameters are melt temperature (E), filling time (B), and gate type (A) followed by part cooling time (C), and pressure holding time (D). The optimum set of parameters can be evaluated from the S/N response diagram in Fig. 3 by selecting the highest level of S/N for each parameter. The result is a combination of A1, B3, C3, D2, and E3. By increasing the ratio of simulated inlet pressure to maximum

International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:10, No:12, 2016

inlet pressure, the possibility of short shot is increased. By using these sets of parameters in SolidWorks Plastics simulation, the ratio of simulated inlet pressure to maximum inlet pressure is 0.3306, which is an acceptable rate.

TABLE III
RESULT OF EXPERIMENTS

Experiment	simulated inlet pressure/ maximum inlet pressure (MPa)	S/N
1	0.5651	4.957
2	0.4848	6.288
3	0.394	8.090
4	0.4185	7.566
5	0.3405	9.357
6	0.4879	6.233
7	0.4738	6.488
8	0.4068	7.812
9	0.3306	9.613
10	0.4249	7.434
11	0.6105	4.286
12	0.5216	5.653
13	0.3628	8.806
14	0.5212	5.659
15	0.4469	6.995
16	0.4308	7.314
17	0.3503	9.111
18	0.5014	5.996

The short shot data in Table III were analyzed via ANOVA and the significance rate of factors were evaluated by percentage of contribution (PC), as shown in Table V. ANOVA computes the quantities such as degree of freedom (f), sum of squares (SS), Mean Square (MS), F-statistic (F), and percentage of contribution (PC). It is clear that significant factors in comparison with response Table IV were mostly the same. The percentage weigh of Melt temperature was the most influential factor with a contribution of 74.25%, followed by filling time at 22.008% and gate type at 3.69%. The contribution of part cooling time and pressure holding time is very low in comparison with melt temperature, filling time and gate type.

TABLE IV
RESPONSE TABLE OF S/N RATIO

	Gate	Filling	Part	Pressure	Melt
Level 1	7.378	6.118	7.094	7.088	5.603
Level 2	6.806	7.436	7.086	7.098	6.938
Level 3	-	7.722	7.097	7.090	8.735
|ΔT|	0.572	1.604	0.011	0.009	3.132

The lowest possibility of short shot in Table III is for trail number nine and 17. Based on the PC of each factor, which is evaluated via ANOVA, it is clear that the reason for having the lowest possibility of short shot in trial number 17 and nine, is because of *B3* and *E3* as significant factors. Although the PC of *C* and *D* is very low in comparison with *A, B* and *E*, the optimum level of each parameter, which leads to a reduction in short shot possibility based on response Table IV, is *A1, B3, C3, D2,* and *E3*. The most significant factors that increase the possibility of short shot are melt temperature and filling time, followed by gate type, based on the percentage of contribution. By referring to the F-distribution statistic table, the F0.05, 1, 17 = 4.45 for evaluating the level of significant factor that is equal to 0.05 (or 95% confidence level). Gate type (A) [F-statistic= 629.3379 > 4.45], filling time (B) [F-statistic= 1876.302 > 4.45], and melt temperature (E) [F-statistic= 6330.234 > 4.45] demonstrates that three factors were significant to the short shot possibility. The simulated inlet pressure for trial number nine and 17 is shown in Fig. 4 and Fig. 5, respectively.

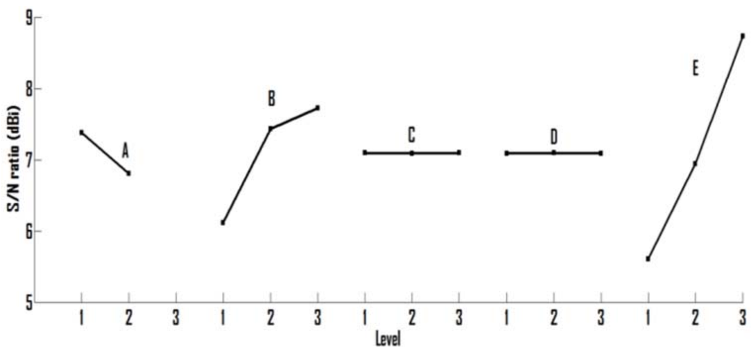

Fig. 3 S/N ratio response diagram based on simulation result

IV. CONCLUDING REMARKS

The combination of simulation with Taguchi experimental design method offers an efficient and easy approach to determine the significant factors which affect the possibility of short shot in injection molding. The proposed approach for the analysis of short shot possibility based on process and geometric parameters was applied in order to reduce the short shot possibility in injection molding before it occurs. The analysis of short shot possibility was conducted via SolidWorks Plastics and FEM and was employed in SolidWorks Plastics for the simulation. L18 orthogonal array of Taguchi for different levels of each factor was used based on the simulation result. The significant level of each factor was evaluated via ANOVA and S/N ratio.

Based on the simulation results and also the statistical analysis of results, the following conclusions can be drawn:

- Melt temperature was the most influential factor with a contribution of 74.25%, filling time with a contribution of 22%, followed by gate type with a contribution of 3.69% for the simulation results. The percentage of contribution for part cooling time and pressure holding time is very low in comparison with that of melt temperature, filling time and gate type which did not consider as significant factors.

TABLE V
ANOVA TABLE

Factor	*f*	SS	*MS*	*F*	*PC (%)*
A	1	1.473472	1.473472	629.3379	3.690974
B	2	8.785992	4.392996	1876.302	22.00847
C	2	0.000412	0.000206	0.088009	0.001032
D	2	0.000328	0.000164	0.070141	0.000823
E	2	29.64202	14.82101	6330.234	74.25178
pool error	8	0.01873	0.033651	-	-
Total	17	39.92096	2.348292	-	-

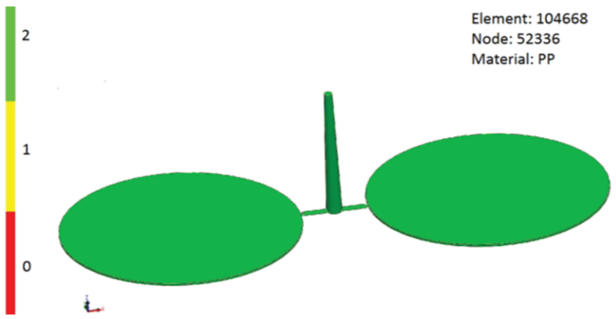

Fig. 4 Ease of fill with minimum level of each parameter

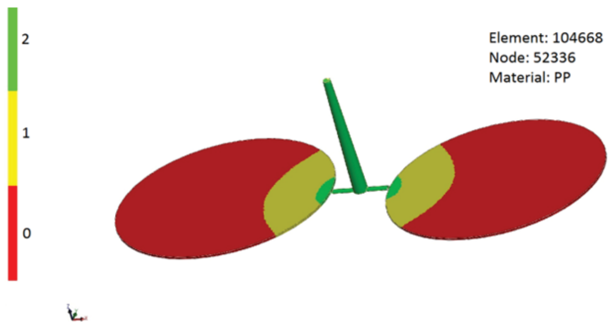

Fig. 5 Ease of fill with 10% lower than fminimum level of each parameter

- By referring to the F-distribution statistic table of simulation results, the F0.05, 1, 17 = 4.45 for evaluating the level of significant factor that equal to 0.05 (or 95% confidence level). Gate type (A) [F-statistic= 629.3379 > 4.45], filling time (B) [F-statistic= 1876.302 > 4.45], and melt temperature (E) [F-statistic= 6330.234 > 4.45] that three factors were significant to the short shot possibility.
- based on response Table IV, the optimum level of each parameter which leads to reduction in possibility of short shot are *gate type at level 1, filling time at level 3, part cooling time at level 3, pressure holding time at level 2,* and *melt temperature at level 3.* Filling time and melt temperature were significant factors which affect the possibility of short shot possibility in the injection molding process.

REFERENCES

[1] Shen, C., L. Wang, W. Cao, and L. Qian, Investigation of the Effect of Molding Variables on Sink Marks of Plastic Injection Molded Parts Using Taguchi DOE Technique. Polymer-Plastics Technology and Engineering, 2007. 46: p. 219-225.

[2] Oktem, H., T. Erzurumlu, and I. Uzman, Application of Taguchi optimization technique in determining plastic injection molding process parameters for a thin-shell part. Materials and Design, 2007. 28: p. 1271-1278.

[3] Chen, W.-C., P.-H. Liou, and S.-C. Chou, An integrated parameter optimization system for MIMO plastic injection molding using soft computing. Int J Adv Manuf Technol, 2014. 73: p. 1465–1474.

[4] Mok, C.K., K.S. Chin, and J.K.L. Ho, An Interactive Knowledge-Based CAD System for Mould Design in Injection Moulding Processes. Int J Adv Manuf Technol, 2001. 17: p. 27–38.

[5] Modrak, V., J. Mandulak, and D. Marton, Investigation of the influence of technological parameters on surface color of plastic parts. Int J Adv Manuf Technol, 2013. 69: p. 1757–1764.

[6] Zhou, H., Computer Modeling for Injection Molding. 2013: A John Wiley & Sons, Inc., Publication.

[7] Chiang, K.-T. and F.-P. Chang, Analysis of shrinkage and warpage in an injection-molded part with a thin shell feature using the response surface methodology. International Journal of Advanced Manufacturing Technology, 2007. 35: p. 468-479.

[8] Hassan, H., An experimental work on the effect of injection molding parameters on the cavity pressure and product weight. Int J Adv Manuf Technol, 2013. 67: p. 675–686.

[9] Zhao, P., H. Zhou, Y. He, K. Cai, and J. Fu, A nondestructive online method for monitoring the injection molding process by collecting and analyzing machine running data. Int J Adv Manuf Technol, 2014. 72: p. 765–777.

[10] Goodship, V., Troubleshooting Injection Moulding. Vol. 15. 2004.

[11] Huang, M.-C. and C.-C. Tai, The Effective Factors in the Warpage Problem of an Injection-Molded Part with a Thin Shell Feature. Journal of Materials Processing Technology, 2001. 110: p. 1-9.

[12] Kitayama, S., R. Onuki, and K. Yamazaki, Warpage reduction with variable pressure profile in plastic injection molding via sequential approximate optimization. Int J Adv Manuf Technol, 2014. 72: p. 827–838.

[13] Li, X.-P., G.-Q. Zhao, and C. Yang, Effect of mold temperature on motion behavior of short glass fibers in injection molding process. Int J Adv Manuf Technol, 2014. 73: p. 639–645.

[14] Moayyedian, M., K. Abhary, and R. Marian. New Design Feature of Mold in Injection Molding for Scrap Reduction. in 2nd International Materials, Industrial, and Manufacturing Engineering Conference, MIMEC2015, 2015. Bali Indonesia: Procedia Manufacturing Elsevier.

[15] Moayyedian, M., K. Abhary, and R. Marian. Improved gate system for scrap reduction in injection molding processes. in 2nd International Materials, Industrial, and Manufacturing Engineering Conference, MIMEC2015. 2015. Bali Indonesia: Procedia Manufacturing Elsevier.

[16] Moayyedian, M., K. Abhary, and R. Marian, Gate design and filling process analysis of the cavity in injection molding process. Advances in Manufacturing: p. 1-11.