Analysis and Simulation of Short Shot Defects in Plastic Injection Molding at Multi Cavities

by Ary Syahriar

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ABSTRACT

This radiator cover mold has been made and has gone through the first pre-production trial stage (T0). However, the product experienced a short shot defect in the 1st cavity. After testing using Moldflow, there is a difference in injection time that is quite long between the 1st cavity and 2nd cavity. There is a need for a new design on the feeding system that can speed up injection time in 1st cavity, so differences in injection time can be minimized. The analysis is done by making variations of the size of the feeding system, which is: runner diameter, width, and thickness of the gate using Taguchi and ANOVA method. The analysis shows that the optimal design of the diameter runner is 8 mm while the size of the wide gate is 10 mm and the thick gate is 0.8 mm. The validation process is repeated using Moldflow with the result of a concise injection time difference is 0.001 s. The new design of feed system able to eliminate the difference in filling time in this product.

CSC Concepts

•Computing methodologies~Modeling and simulation~Model development and analysis~Model verification and validation

Keywords

Injection time, Feed system, Short shot

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1 Introduction

The use of plastic is now increasingly massive, marked by the amount of plastic production currently reaching more than 230 million tons/year, 2020 continues to increase this year to 400 million tons with a growth rate of around 5% per year [1,2]. There is a study that states the consumption of raw material is based on weight, when compared with other materials, such as aluminum, steel, rubber, copper, zink, etc. It is reasonable, because plastic is easy to form and low processing costs [3]. Plastic are increasingly varied, because of the nature of being easily constrained, cheap production processes, and increasing physical properties.

Mold Cover Radiator is a type of multi-cavity. After going through the pre-production test phase, several problems were found in the mold. One of the biggest problems is the significant injection time difference between 1st cavity and 2nd cavity. Injection time difference affects one product that is not fully loaded while on the other hand the product is fully charged [4].

An incomplete part in a plastic product is considered a short shot. The problem is easily recognized as a part that is not fully loaded, one of which is influenced by some processing parameters that are not set properly. This might include transfer points, melt or mold temperatures, packing pressures and other variables. However, it can also be influenced by the design of the gate which was not ideal [5]. Short shot defects that occur in the radiator cover product as shown in Figure 1:

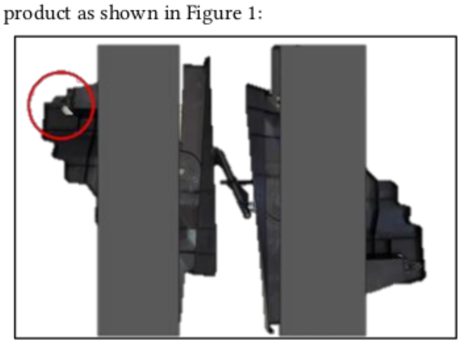

Figure 1 Short shot defects in radiator cover

Feeding system is a feeder system that regulates the distribution of plastic material flow from the machine into a mold consisting of a sprue system, runner system and gate system [6]. Redesign of feeding system aims to improve the injection time difference in plastic products [5]. So, in order to optimize the feeding system design, it is necessary to conduct a study of optimizing the feeding system design of the runner and gate system to produce a product without short shot defects in the 1st cavity and 2nd cavity.

2 Research Methodolgy

2.1 Steps for Testing the Feeding System

The stages of the testing process carried out in this study are explained through the following flowcharts as shown in Figure 2:

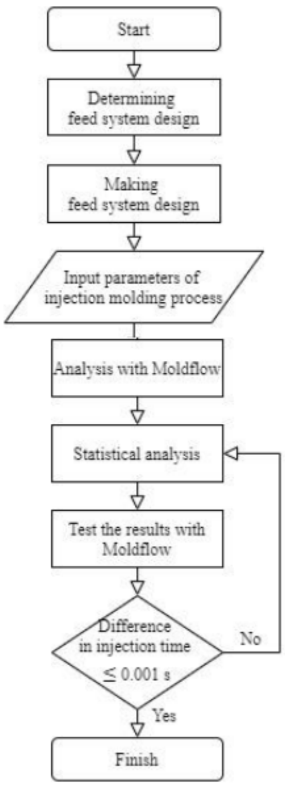

Figure 2 Flow chart of Optimization Feeding System to Injection Time in Radiator Cover Mold

2.2 Injection Process Parameters

These parameters are needed to be able to see the filling phase using Moldflow. Parameters for simulation of filling time are determined as demonstrated in Table 1.

Table 1 Parameter simulation filling time of radiator cover

Parameter	Value	Unit
Melt Temperature	220	°C
Mold Temperature	50	°C
Flowrate	145	cm^3/s
Injection Pressure	60	MPa
Packing Pressure	84	MPa
Packing Time	10	s

2.3 Feeding System Testing Response

Simulation of injection time response is divided into three categories, that is injection time at 1st cavity (v1), 2nd cavity (v2), and difference between the two (d). The following is the result of filling analysis in the initial conditions as shown in Figure 3:

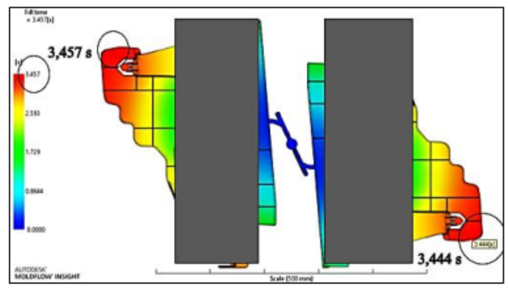

Figure 3 The initial simulation of injection time on the radiator cover

Injection time at (v1) is 3,457 s while at (v2) is 3,444 s. These results indicate at (d) is 0.013 s. To be optimal, if the injection time between (v1) and (v2) approaches nominal 3.444 s and (d) approaches or equals 0 s (d ≤ 0,002 s).

2.4 Testing Materials

2.4.1 The cover radiator mold material

The mold material used is P-20 type material in AISI standard. This type of material is commonly used for tool steel, following the specifications of the material as demonstrated in Table 2.

Table 2 Specifications of P-20

Characteristics	Value	Unit
Mold Density	7,8	g/cm^3
Mold Specific Heat	460	J/kg°C
Mold Thermal	29	W/m°C
Elastic Modulus (E)	205.000	MPa
Poissons ratio (v)	29	%

2.4.2 The cover radiator material

The radiator cover material is a type of polypropylene (PP) with the following material characteristics as shown in Table 3.

Table 3 Specifications of polypropylene

Characteristics	Value	Unit
Melt Flow Index	38	g/10min
Mold Shrinkage, MD	0.015	mm/mm
Mold Shrinkage, TD	0.017	mm/mm
Density	900	kg/m³
Tensile Strength at Yield	23.05	MPa
Tensile Strength at Break	50	MPa
Flexural Modulus	1150	MPa
Rockwell Hardness	R 86	-
DTUL @ 66 psi	122	°C

Source: Injection Molding Handbook, Rosato, 2000

3 Simulation and Experimental Results

3.1 Determination design of the diameter runner

The diameter of the runner taken is the largest diameter of the advice given in table 4, which is 9.525 mm which is then rounded to 10 mm. Table 4 shown recommendations of runner diameters.

Table 4 Recommended diameter of runners for several types of plastic material

Plastic Material	Range Diameter [Inch]		Range Diameter [mm]	
ABS, SAN	0,187	0,375	4,750	9,525
Acetal	0,125	0,375	3,175	9,525
Acrylic	0,312	0,375	7,925	9,525
Cellulosic	0,187	0,375	4,750	9,525
Ionomer	0,093	0,375	2,362	9,525
Nylon	0,062	0,375	1,575	9,525
Polycarbonate	0,187	0,375	4,750	9,525
Polyester	0,187	0,375	4,750	9,525
Polyethylene	0,062	0,375	1,575	9,525
Polypropylene	0,187	0,375	4,750	9,525
PPO	0,250	0,375	6,350	9,525
Polysulfone	0,250	0,375	6,350	9,525
Polystyrene	0,125	0,375	3,175	9,525
PVC	0,125	0,375	3,175	9,525

Source: Injection Molding Handbook, Rosato, 2000

3.2 Determination design of the diameter runner

The gate is the entrance of melting material to plastic products, this has the direct effect of controlling the flow process in the plastic mold cavity which ensures the product is fully filled so that mechanical properties, dimensional stability, and product appearance can be achieved as desired. [7]. One type of gate that is simple and uses quite a lot is the edge gate. The edge gate has a rectangular cross-section by taking into the width and height as calculated [8]. So, it is very important to determine the dimensions of the gate itself. Calculations for edge gates through Eq. (1) and (2) [4].

$$w = \frac{n\sqrt{a}}{30} \tag{1}$$

$$w = 10\,mm$$

Note:

W = *Width of the gate [mm],*

n = *Constant of Polypropylene*

a = *surface area of the plastic product section [mm²]*

$$h = nt \tag{2}$$

$$h = 0{,}8\,mm$$

Note:

h = *Gate height [mm]*

t = *Average thickness of product [mm]*

Based on the calculation results of the gate, the obtained size for the edge gate that has a width of 10 mm and a height of 0.8 mm.

3.3 Taguchi Method

The diameter of the runner taken is the largest diameter of the advice given in table 4, which is 9.525 mm which is then rounded to 10 mm. Table 4 shown recommendations of runner diameters.

3.3.1 Selection of the control factors

Analysis for design changes was made based on the Taguchi method. The Taguchi method is a comprehensive quality strategy that carries out a number of experiments using orthogonal arrays and building endurance during the design phase [9-11].

There are three main stages namely system design, parameter design, and tolerance design. System design is to identify the basic elements of the design itself, which will produce the desired output. Design parameters are used as the most optimal parameter determinant by considering the design elements of each parameter in order to obtain product targets. Then, design tolerance is used to identify design components that affect product quality and set tolerance limits at the level of design variation. [12].

3.3.2 Selection of the level factor in the design parameter

These three factors are analyzed in this study there are: runner, gate width, and gate thickness. Following are shown in Table 5.

Table 5 Factor level

Level	Control Factor		
	Diameter runner (A) [mm]	Wide gate (B) [mm]	Thick gate (C) [mm]
1	8	8	0,6
2	10	10	0,8
3	12	12	1

Orthogonal arrays can be used as a medium to organize matrix experiments, to evaluate the effects of a factors together and are an effective tool [13]. The use of orthogonal array includes all parameters with a minimum of experiments, allocation of control parameters and design variables to the column and transfers the results of the experiment to the real parameter settings [10,14].

3.3.3 Selection of the orthogonal array

Based on method for orthogonal array L9 or 33. The pattern shown on Table 6, as follows:

Table 6 Design variations of feeding system based on orthogonal array

Exp.	Control Factor		
No	A (mm)	B (mm)	C (mm)
1	8	8	0,6
2	8	10	0,8
3	8	12	1
4	10	8	0,8
5	10	10	1
6	10	12	0,6
7	12	8	1
8	12	10	0,6
9	12	12	0,8

3.4 Signal to noise (S/N) ratio approach

The signal to noise ratio (S/N) is used to determine the quality characteristics of each problem. The S/N ratio has three phases: the smaller the better, the best nominal, and the bigger the better [10].

3.5 Simulation Results Data Using Moldflow

The design that has been made is then tested again using Moldflow. The result of simulation injection time response on the 1st and 2nd cavity shown on Table 7, as follows:

Table 7 The results of simulation injection time

Exp.	At 1st cavity (v1)		At 2nd cavity (v2)	
No	Exp. Result (S)	S/N 3,444 Better	Exp. Result (S)	S/N 3,444 Better
1	3,446	53,979	3,475	30,173
2	3,446	53,979	3,445	60
3	3,46	35,918	3,438	44,437
4	3,481	28,636	3,505	24,293
5	3,496	25,68	3,488	27,131
6	3,471	31,373	3,519	22,499
7	3,529	21,412	3,539	20,446
8	3,524	21,938	3,551	19,412
9	3,532	21,11	3,539	20,446

The result of injection time response on the difference between 1st cavity and 2nd cavity shown on the Table 8, as follows:

Table 8 Difference injection time at 1st cavity and 2nd cavity

Exp	Difference (d)	
No	Exp. Result (s)	S/N 0 better
1	-0,029	30,752
2	0,001	60
3	0,022	33,152
4	-0,024	32,396
5	0,008	41,938
6	-0,048	26,375
7	-0,01	40
8	-0,027	31,373
9	-0,007	43,098

The results of each sub feeding system in 1st cavity against injection time indicated the best level marked in blue with an injection time of 3,446 s and the worst level marked in red with an injection time of 3,532 s. While, the results on 2nd cavity are shown the best level with injection time of 3,445 s and the worst level with injection time of 3,551 s.

In this study using the S/N-type of nominal better is the highest S/N shows the most optimal nominal injection time.

3.5.1 Analysis of the effect of runner diameter on the difference of injection time

Figure 4 shows the results of calculations of the influence of runner diameter on differences in injection time in 1st cavity, 2nd cavity, and between cavities.

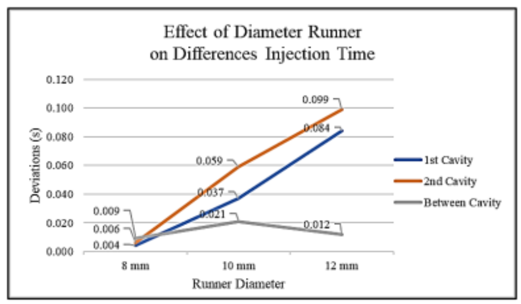

Figure 4 Modelling of Effect of Diameter Runner on Differences Injection Time

3.5.2 Analysis of the effect of gate width on the difference of injection time

The effect of gate width on the difference of injection time in 1st cavity, 2nd cavity, and between cavities are shown in Figure 5 as follows:

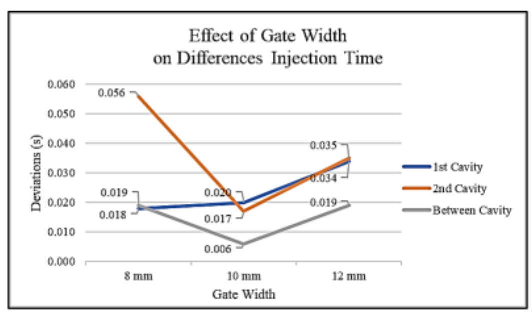

Figure 5 Modelling of Effect of Gate Width on Differences Injection Time

3.5.3 Analysis of the effect of gate thickness on the difference of injection time.

Figure 6 shows the result calculation of the effect of gate thickness on the difference of injection time in the 1st cavity, 2nd cavity, and between cavities.

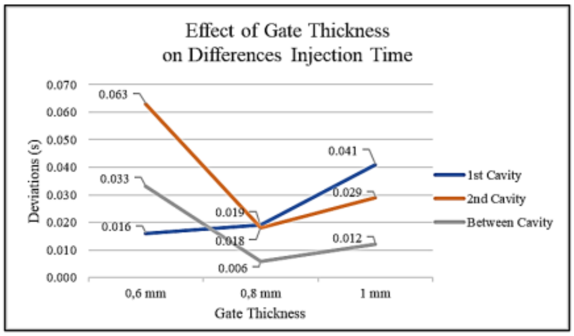

Figure 6 Modelling of Effect of Gate Thinckness on Differences Injection Time

3.6 Analysis of variance (ANOVA Method)

ANOVA method is used to determine the level of influence of changes or factor effects of each sub feeding system on each response. This method is also used to test whether variations are acceptable or not.

3.6.1 Determination of nominal variation test

It is assumed that in the data analysis of the results of this test the importance level of 98% was chosen, $\alpha = 0.02$. This means that if the P value of a sub feeding system is less than 2%, it is assumed that there are variations due to changes in the sub feeding system can be ignored. In the ANOVA method ignoring a control factor is usually called accepting H0 and rejecting H1, and vice versa if receiving a control factor is usually called accepting H1 and rejecting H0.

3.6.2 Factor effect on injection time in 1st cavity, 2nd cavity, and between cavities

The results of the factor effect (*P*) can be calculated with degrees of freedom (*DoF*), number of squares (*SoS*), or number of squares between groups (*SSG*) and mean squares (*MSG / V*) [4]. The formula used is shown by Eq. (4), (5), (6), and (7), as follows:

$$DoF = k - 1 \tag{4}$$

$$SSG = \sum_{i=1}^{k} ni(\bar{x}_i - \bar{x})^2 \tag{5}$$

$$MSG = \frac{SSG}{Dof} \tag{6}$$

$$P = \frac{SSG}{\sum SSG} . 100\% \tag{7}$$

Note:
k = Number to be examined on the independent variables
ni = Sample size of population *i*, x_i *is i - i* measurement
x = Overall mean (of all data values)

Factor effect is the level of influence of a control factor on a response. These are the influence factors on injection time in each cavity. The results of the factor effects on injection time at 1st cavity is shown in Table 9, as follows:

Table 9 Factor effect on injection time on 1st cavity

Factor Effect on Injection Time in 1st Cavity							
Control Factor	Level 1	Level 2	Level 3	DoF	SoS	V	P
Runner	8	10	12	2	376	188	87%
Gate width	8	10	12	2	16	8	4%
Gate thickness	0,6	0,8	1	2	38	19	9%

The results of the factor effects on injection time at 2nd cavity is shown in Table 10, as follows:

Table 10 Factor effect on injection time on 2nd cavity

Factor Effect on Injection Time in 2nd Cavity							
Control Factor	Level 1	Level 2	Level 3	DoF	SoS	V	P
Runner	8	10	12	2	348	174	75%
Gate width	8	10	12	2	56	28	12%
Gate thickness	0,6	0,8	1	2	60	30	13%

The results of the factor effects on injection time difference between cavities are shown in Table 11, as follows:

Table 11 Factor effect on injection time differences between cavities

Factor Effect on Injection Time in Between Cavities							
Control Factor	Level 1	Level 2	Level 3	DoF	SoS	V	P
Runner	8	10	12	2	30	15	14%
Gate width	8	10	12	2	68	34	31%
Gate thickness	0,6	0,8	1	2	124	62	55%

3.7 Calculation of variation of optimal control factors

Data analysis of responses from the 1st cavity, 2nd cavity, and between cavities can be determined by Pareto calculation. The following is the result of Pareto filled with data on the number of S/N ratios for each level of the sub feeding system. Table 12 as shown the result of calculation of Pareto optimal conditions, as follows:

Table 12 Calculation of Pareto optimal conditions

	Respon of Control Factor		Injection Time v1	Injection Time v2	Injection Time d	Sum	Optimal Value
Parameter	Runner diameter	8	144	135	124	403	8 [mm]
		10	85	74	101	260	
		12	64	60	114	238	
	Gate width	8	104	75	103	282	10 [mm]
		10	102	107	133	342	
		12	88	87	103	278	
	Gate thickness	0,6	107	72	88	267	0,8 [mm]
		0,8	104	105	135	344	
		1	83	92	115	290	

The biggest value of the control factor of the diameter runner is at level 1, which is 8 mm, the biggest value of the control factor of the gate width is at level 2, which is 10 mm, and the biggest value of the control factor of the gate thickness is at level 2, which is 0.8 mm.

4 Result of Testing Analysis

4.1 Determination design of the diameter runner

The final test was carried out using Moldflow. Figure 7 shows the simulation results based on the control factor of injection response time as follows:

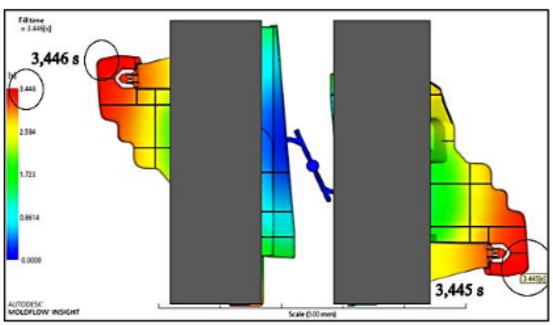

Figure 7 Simulation Test Results of the Final Injection Time Analysis on the Radiator Cover

The analysis was carried out using a sub feeding system on the 1st cavity with a runner diameter of 8 mm, a gate width of 10 mm, and a gate thickness of 0.8 mm. Figure 7 shows that the injection time determines the optimal value. Where the injection time value in 1st cavity is 3,446 s and the injection time in 2nd cavity is 3,445 s. So, the difference injection time between cavities is 0.001 s. The following is a Table 13 that considers before and after the analysis of injection time.

Table 13 Comparison of injection time conditions before and after analysis

Condition	Injection time at 1st cavity	Injection time at 2nd cavity	Difference between cavities
Before	3,457 s	3,444 s	0,013 s
After	3,446 s	3,445 s	0,001 s

5 Conclusions

The radiator cover mold has a problem of unbalanced injection time between cavities. This research proves that changing the feeding system design can correct these problems. Based on the previous discussion which refers to the main problem, it can be concluded that the design of a new feeding system is optimal for use in this mold with the following specifications:

1. The diameter of the runner is fixed at the size of 8 mm.
2. The gate width at the 1st cavity from 8 mm is enlarged to 10 mm.
3. The Gate thickness at the 1st cavity from 1 mm is reduced to 0.8 mm.

The results of the change in sub feeding system are as follows:

1. Injection time in the 1st cavity is 0.011 s, faster than the previous 3.457 s to 3.446 s.
2. Injection time in the 2nd cavity is 0.001 s, longer than the previous 3.444 s to 3.445 s.
3. Injection time difference between the two cavities is shorter than before, which is 0.012 s to 0.001 s.

REFERENCES

[1] D. Braun, Journal of Polymer Science Part A: Polymer Chemistry Edition, 2004, 42, 578.

[2] B.R.T. Simoneit, P.M. Medeiros and B.M. Didyk, Environmental Science & Technology, 2005, 39, 6961

[3] Zhou H., Computer modeling for injection molding: simulation, optimization, and control. Wiley, Hoboken, 2012.

[4] Moayyedian, M., Abhary, K. & Marian, R., Gate design and filling process analysis of the cavity in injection molding process. Adv. Manuf. 4, 123–133, 2016.

[5] Olmsted Bernie, A., & Martin Davis E., "Practical Injection Molding", New York, Marcel Dekker, Inc., 2001.

[6] Kazmer, D.O., "Injection Mold Design Engineering", Munich, Carl Hanser Verlag, 2007.

[7] Dai, W., P. Liu, and X. Wang, An improved pin gate and its flow pattern in the cavity. Journal of Injection Molding Technology, 2002.

[8] Pye R., Injection mold design: a textbook for the novice and a design manual for the thermoplastics industry. Wiley, New York, 1989.

[9] Shen C, Wang L, Cao W et al., Investigation of the effect of molding variables on sink marks of plastic injection molded parts using Taguchi DOE technique. Polym Plast Technol Eng 46(3):219–225, 2007.

[10] Oktem H, Erzurumlu T, Uzman I, Application of Taguchi optimization technique in determining plastic injection molding process parameters for a thin-shell part. Mater Des 28:1271–1278, 2007.

[11] Yang K., El-Haik B.S.,Design for six sigma: a roadmap for product development. McGraw-Hill Companies, New York, 2009.

[12] Taguchi, G., El Sayed, M. & Hsaing, C. Quality engineering and production systems. McGraw-Hill, New York, 1989.

[13] Dai W, Liu P, Wang X. An improved mold pin gate and its flow pattern in the cavity. J Inject Molding Technol 6(2):115, 2002

[14] Beaumont J.P., Runner and gating design handbook. Hanser, Munich, 2004.

[15] Rosato, D.V. & Rosato, Marlene G., "Injection Molding Handbook", Springer US, Kluwer Academic Publishers, 2000.

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