

Warpage Improvement of Thick Component Using Taguchi Optimization Method for Single and Double Gates in Injection Molding Process

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Abstract: Minimizing a warpage issue in plastic injection molding process were widely investigated by researcher and manufacturer of plastic product. Objective of this paper is to examine the various injection parameters and identify the best setting for single and double gate, which affect the warpage for thick component using Taguchi and ANOVA methods. Mold Temperature, Melt Temperature, Packing Pressure and Packing Time are the selected parameter that used in this study. These experiments were performing by Autodesk Moldflow Insight (AMI) software based on L9 Orthogonal Array designed by Taguchi. Effects of single and double gates to the warpage formation also were compared. The results show that Taguchi method is capable to minimize the warpage deflection. Moreover, double gate design was better than single gate in minimizing the warpage deflection.

Key words: injection molding; Taguchi; ANOVA; warpage

INTRODUCTION

Plastic injection molding process is one of the most importance methods for forming a variety shape of plastic products. About 70% of the plastic components and products were manufacture using plastic injection molding process. The properties of molded part were categorized into mechanical properties, optical properties, thermal properties and aesthetic properties. Many researchers had investigated to improve all types of properties in order to improve the quality of the products.

There are some techniques for improvement of mechanical and aesthetic properties of plastic injection molding products. The first techniques was Vibrational Assisted Injection Molding (VAIM) that used some mechanical assistance like vibration during injection of melt material to the mold in order to get a better strength and surface finish of the products (Tom *et al.* 1980; A. Kikuchi *et al.* 2006; Li and Shen 2008). Second technique was used Rapid heat cycle molding (RHCM) where mold was heated rapidly during filling and packing phase to assist the melt flow easily to the mold cavity, then during cooling phase, the mold will cold due to water flow in water line (G. Wang *et al.* 2013; G. Wang *et al.* 2012; Zhao *et al.* 2011). This technique was investigates to improve both mechanical properties and aesthetic properties of products. Furthermore, some researcher like Ersoy and Nugay (2004) and Lu *et al.* (2004) had adding some fillers in to virgin material with the aim of increasing the strength compared to virgin material, but the results shown conversely. The techniques that mentions above were occasionally be used in industries because of it need more investment on money, complicated mole and required higher skill and techniques to make it operated well. Therefore, parameters optimization techniques were widely used to improve the quality of molded parts. Nowadays, a lot of optimization method that can be used such as Taguchi, Response Surface Modeling (RSM), Genetic Algorithm (GA), Artificial Neural Network (ANN) and so on, for variety of studied areas. Taguchi optimization method was used by Liu *et al.* (2000), Ozcelik (2011) and Hongsheng Li *et al.* (2006) in their investigation to improve strength of the products, but Tang *et al.* (2007), Shayfull *et al.* (2011) and Erzurumlu and Ozcelik (2006) focus on warpage improvement as well as aesthetic properties for thin component. The results show that Taguchi optimization method was suitable for improvement of component strength and warpage. Besides, other optimization method were also suitable such as RSM that had be used for warpage improvement by Kurtaran and Erzurumlu (2005) who founded that warpage can improve about 46% compared to conventional setting. Moreover, ANN, GA and Back Propagation (BP) neural-network optimization methods also influential for improvement of warpage and strength of products. (B. Ozcelik and T. Erzurumlu 2006; Yin *et al.* 2011; Deng *et al.* 2008)

In this study, Taguchi optimization method was chosen as an improvement techniques to improve the aesthetic properties (minimize warpage) problem for thick product. Additionally, two type of gating system (single gate and double gate) were proposed and the warpage results were compared each other in order to get

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the best parameter setting for lowest deflection of warpage. This experiment was analyzed using Autodesk Moldflow Insight software.

Experimental Method:

Mold Design:

The importance aspect in mold design are gating system design and cooling channel layout. Before deciding a gating system design, the importance thing that should be consider are type of mold either two plate or three plate and also injection molding size.

In this study, a two plate mold was chosen and the mold design was refer to ISO 294-1:1999(E). So, all suggestion in that document had been followed. Two types of gating system are shown in Figure 1 (a) and (b) respectively. The thickness of component is 4mm and the diameter of cooling line is 8mm.

For gating system and components, 3D mesh was used for both single and double gates. As much as 345,914 of tetrahedral elements were created for double gates gating system and 333,939 for single gates where mesh thickness was set at 2.5mm for both of them. Beam elements were used for cooling lines.

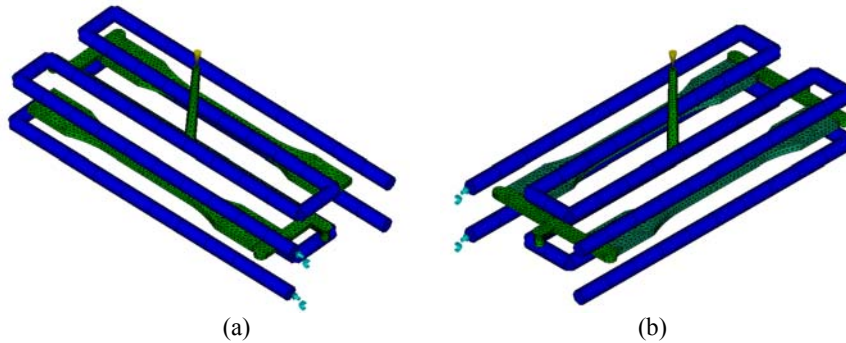


Fig. 1: Mold Design for; (a) Single Gate, and (b) Double Gates.

Mold Material and Injected Material:

P20 Mold Steel was chosen for mold insert material for this study. PC/ABS model Bayblend T85 from Bayer Material has a plastic material that had injected inside the mold cavity. Properties for both types of material are shown in Table 1 and 2 respectively.

Table 1: Physical and Mechanical Properties of PC/ABS.

Properties	Value
Specific heat, C_p (J/kg°C)	2232
Elastic modulus, E (MPa)	2.573×10^3
Poisson's ratio, ν	0.4
Thermal conductivity, K (w/m°C)	0.18

Table 2: Properties of P20 Mold Steel.

Properties	Value
Mold density, (g/cm ³)	7.8
Mold specific heat (J/kg°C)	460
Thermal conductivity, K (w/m°C)	29
Elastic modulus, E (MPa)	$2.0e5$
Poisson's ratio, ν	0.33
Mold coefficient of thermal expansion (1/C)	$1.2e-5$

Experiment Set-up:

There are many factors that affect the warpage problem in plastic injection molding process. From others studied like Tang *et al.* (2007) and Shayfull *et al.* (2011), only four factor selected to investigate in this experiment. Mold temperature, melt temperature, packing pressure and packing time were founded that provides significant effect for warpage problem. Based on these factors, L9 Orthogonal Array (OA) was chosen for both single gate and double gates. The selected levels from each factor were shown in Table 3 and the combination parameter of OA for each trial was shown in Figure 4. This OA was used for both type of gates and consists of 9 experiment trial for every single gate.

Table 3: Three Level of Effective Factor of Difference Gate.

Factors	Single Gate			Double Gates		
	1	2	3	1	2	3
Mold temperature, A (°C)	60	60	70	80	70	80
Melt temperature, B (°C)	240	240	260	280	260	280
Packing pressure, C (MPa)	40	40	50	60	50	60
Packing time, D (s)	16	16	18	20	18	20

Table 4: Taguchi Orthogonal Array of Difference Gate.

Gate Type Parameters	Single Gate				Double Gates			
	A	B	C	D	A	B	C	D
Trial 1	60	240	40	16	40	220	30	10.0
Trial 2	60	260	50	18	40	245	40	12.5
Trial 3	60	280	60	20	40	270	50	15.0
Trial 4	70	240	50	20	65	220	40	15.0
Trial 5	70	260	60	16	65	245	50	10.0
Trial 6	70	280	40	18	65	270	30	12.5
Trial 7	80	240	60	18	90	220	50	12.5
Trial 8	80	260	40	20	90	245	30	15.0
Trial 9	80	280	50	16	90	270	40	10.0

Analysis of Results

a) Taguchi Method:

Taguchi method is applied to determine the output warpage based on the process parameters setting. The measured deflection of warpage and signal to noise ratio (S/N) values are shown in Table 5 and 6 respectively. The S/N ratio is used by Taguchi to measure the quality characteristic deviating from the desire value (Tuncay Erzurumlu and Babur Ozelik 2006). In this study, the smallest of S/N ratio will consequence the best quality of results. The equation to obtain the values of S/N for “smaller the better” is shown below:

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

Where Mean Square Deviation (MSD) is:

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

Where, y = Observation
 n = No. of tests in a trial

Table 5: Results for Warpage Deflection for Each Gate.

Gate Type Parameters	Single gate					Double Gates				
	Mold temp., A (°C)	Melt temp., B (°C)	Packing pressure, C (MPa)	Packing time, D (s)	Warpage Deflection (mm)	Mold temp., A (°C)	Melt temp., B (°C)	Packing pressure, C (MPa)	Packing time, D (s)	Warpage Deflection (mm)
Trial 1	60	240	40	16	0.8832	40	220	30	10.0	0.3470
Trial 2	60	260	50	18	1.0920	40	245	40	12.5	0.3201
Trial 3	60	280	60	20	0.9291	40	270	50	15.0	0.2699
Trial 4	70	240	50	20	0.8207	65	220	40	15.0	0.3578
Trial 5	70	260	60	16	0.9700	65	245	50	10.0	0.3015
Trial 6	70	280	40	18	0.8182	65	270	30	12.5	0.3492
Trial 7	80	240	60	18	0.8760	90	220	50	12.5	0.3359
Trial 8	80	260	40	20	0.7082	90	245	30	15.0	0.3936
Trial 9	80	280	50	16	0.7918	90	270	40	10.0	0.3463

Table 6: The response table of S/N ratio for Difference Gate.

Gate Type Parameters	Single Gate				Double Gates			
	Mold temp., A (°C)	Melt temp., B (°C)	Packing pressure, C (MPa)	Packing time, D (s)	Mold temp., A (°C)	Melt temp., B (°C)	Packing pressure, C (MPa)	Packing time, D (s)
Level 1	1.3150	0.3177	1.9395	1.1237	9.1988	10.1545	14.4843	9.6062
Level 2	0.8323	1.2412	0.9932	0.8130	9.4691	15.1674	9.3441	13.7842
Level 3	1.4698	2.0582	0.6844	1.7840	15.5825	8.9285	10.4220	9.4673
Difference	0.6374	1.7405	1.2551	0.9710	6.3837	6.2388	5.1402	4.3169

b) Analysis of Variance (ANOVA):

ANOVA analysis was done to find the significant factors that contribute to the warpage problem. The variables involved include degree of freedom (f), sums of square (S), variance (V) and F-ratio (F), in order to get

highest value of percentage contribution (P).

ANOVA analysis starts with calculation for degree of freedom, f as an example below:

Total degree of freedom, f :

$$f_T = N - 1 \quad \blacksquare 9 - 1 = 8 \quad (3)$$

where N is the number of trial

For Factor A, f_A

$$f_A = k_A - 1 \quad \blacksquare 3 - 1 = 2$$

where k_A is the number of level for factor A

For Error, $f_E = f_T - (f_A + f_B + f_C + f_D)$

$$\blacksquare 8 - (2 + 2 + 2 + 2) = 0 \quad (4)$$

Then the Sum of squares for all factors is calculated as example as shown below:

Sum of squares, S :

$$S_T = (z_{21}^2 + z_{22}^2 + \dots + z_{29}^2) - \frac{(z_{21} + z_{22} + \dots + z_{29})^2}{N} \quad (5)$$

$$\blacksquare (0.8888^2 + 1.088^2 + 0.8281^2 + \dots + 0.7818^2) - \frac{(0.8888 + 1.088 + 0.8281 + \dots + 0.7818)^2}{9}$$

$$\blacksquare 70.16 \times 10^{-2} - 68.18 \times 10^{-2}$$

$$\blacksquare 100 \times 10^{-2}$$

For Factor A, S_A

$$S_A = \frac{(\sum A_1)^2}{k_A} + \dots + \frac{(\sum A_4)^2}{k_A} - \frac{(z_{21} + z_{22} + \dots + z_{29})^2}{N}$$

$$S_A = \frac{(0.8888 + 0.8287 + 0.8760)^2}{3} + \frac{(1.088 + 0.8700 + 0.7082)^2}{3} + \frac{(0.8281 + 0.8182 + 0.7818)^2}{3} - \frac{(0.8888 + 1.088 + 0.8281 + \dots + 0.7818)^2}{9}$$

$$\blacksquare 10.14 \times 10^{-2}$$

For Error, S_E

$$S_E = S_T - (S_A + S_B + S_C + S_D) \quad (6)$$

$$= 100 \times 10^{-2} - (10.14 \times 10^{-2} + 46.78 \times 10^{-2} + 28.06 \times 10^{-2} + 18.07 \times 10^{-2})$$

$$= 0$$

The values of variances for all factors are then calculated. The example of calculating variance is shown:

For Factor A, $V_A = \frac{S_A}{f_A} \quad (7)$

$$\blacksquare \frac{10.14 \times 10^{-2}}{2} = 5.07 \times 10^{-2}$$

For Variance Error, $V_E = \frac{S_E}{f_E} = \frac{0}{0} = 0$

Then the F-ratio, F for all factors is calculated and the example of calculation is shown below:

For Factor A, $F_A = \frac{V_A}{V_E}$ (8)

F_A, F_B, F_C and F_D can not be determined as $V_E = 0$.

After that the Percentage Contribution, PA for all factors is calculated and the example of the calculation is shown below.

For Factor A, $F_A = \frac{S_A}{S_T} \times 100$ (9)

$$= \frac{10.14 \times 10^{-3}}{100 \times 10^{-3}} \times 100 = 10.14\%$$

c) **Conformation Test:**

A conformation test is then conducted based on the results from Taguchi analysis performed before. The purpose of conformation test is to validate the results from Taguchi optimization technique.

RESULTS AND DISCUSSION

Optimization Using Taguchi Method:

The optimal set of process parameter for single and double gates is shown in Table 7. The best set of parameters can be determined by selecting the significant factors that affects to warpage in Table 6. The significant factor can be found by selecting the highest S/N ratio for every parameter stated. Results for S/N response also had been visualized in Figure 2, for each parameters represent by A, B, C and D.

Table 7: Parameters optimized by using Taguchi method.

Material	The Best Parameter Setting			
	Mold temperature, A (°C)	Melt temperature, B (°C)	Packing pressure, C (MPa)	Packing time, D (s)
Single gate	80	280	40	20
Double gates	90	245	30	12.5

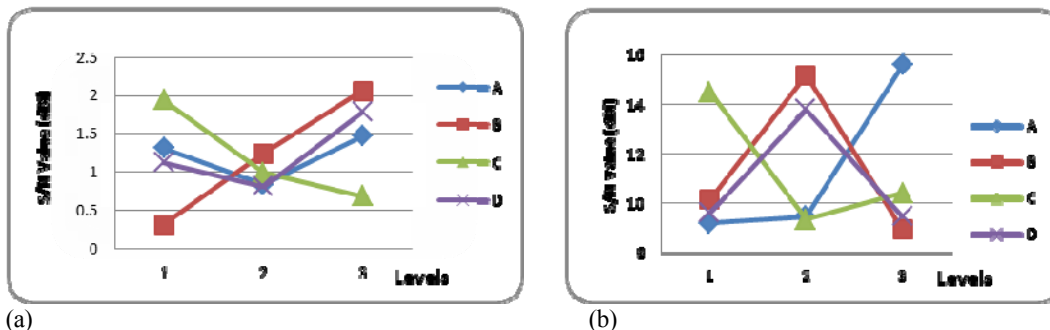


Fig. 2: Effects of Process Parameter on Warpage using (a) Single gate, and (b) double gates.

ANOVA Analysis:

From Table 8 and 9, the results of maximum percentage contribution (P) show the most significant factor that affect the warpage value. Thus, for single gate, the highest factor that contributes towards warpage is melt temperature (46.73%), followed by packing pressure (25.06%) and the least contribution is mold temperature (10.14%). Moreover, from observation, the most significant results tested on double gate are mold temperature (35.79%), and packing pressure being the least (11.18%).

Table 8: ANOVA Results for Single Gate.

Source	f	S	V	F	P(%)
Mold Temperature, A	2	10.14 x 10 ⁻³	5.07 x 10 ⁻³	-	10.14
Melt temperature, B	2	46.73 x 10 ⁻³	23.37 x 10 ⁻³	-	46.73
Packing pressure, C	2	25.06 x 10 ⁻³	12.53 x 10 ⁻³	-	25.06
Packing time, D	2	18.07 x 10 ⁻³	9.03 x 10 ⁻³	-	18.07
Pooled error	0	0			100
Total	8	100 x 10 ⁻³			

Table 9: ANOVA Results for Double Gate.

Source	<i>f</i>	<i>S</i>	<i>V</i>	<i>F</i>	<i>P</i> (%)
Mold Temperature, A	2	29.32 x 10 ⁻³	14.66 x 10 ⁻³	-	35.79
Melt temperature, B	2	22.93 x 10 ⁻³	11.47 x 10 ⁻³	-	28.00
Packing pressure, C	2	9.16 x 10 ⁻³	4.8 x 10 ⁻³	-	11.18
Packing time, D	2	20.50 x 10 ⁻³	10.25 x 10 ⁻³	-	25.03
Pooled error	0	0			100
Total	8	38.11 x 10 ⁻⁵			

Conformation Test:

From S/N ratio in Taguchi optimization method, a set of best combination parameter to minimize a warpage have been suggested in Table 7 for both gates design. From those parameters, a validation process was done using conformation test. From the results in Table 10, warpage deflection value was decrease compare to the other trial run for both single and double gates. Therefore, Taguchi optimization technique can be used for warpage optimization for thick products.

Table 10: Conformation Test Results.

		Single gate	Double gate
Factors	Mold Temperature, °C	80	90
	Melt Temperature, °C	280	245
	Packing Pressure, MPa	40	30
	Packing Time, s	20	12.5
Warpage, mm		0.7025	0.2567

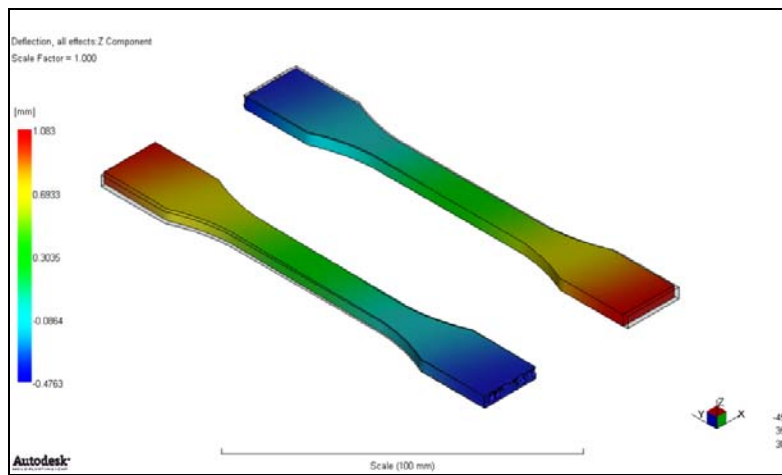


Fig. 3: Warpage deflection using single gate.

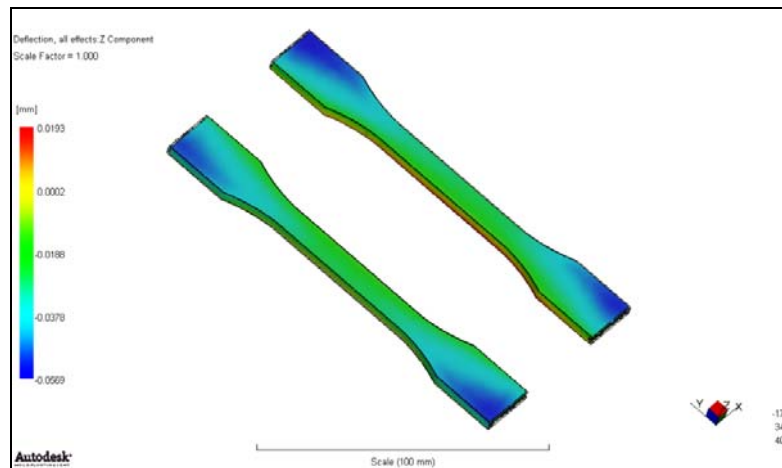


Fig. 4: Warpage deflection using double gates.

Comparison of Single and Double Gates:

Figure 3 and 4 are the results of warpage deflection in using single and double gates. The values of warpage for both of them were much difference. Deflection of the component using single gate are much higher than double gate. Thus, the warpage problem can be improved when double gate is used.

Conclusions:

The best set of parameters for minimizing the warpage problem of thick product had been identified using Taguchi method by analyzing the signal-to-noise (S/N) ratio for each parameter used. A combination of parameters for each type of gate was verified using conformation test. From the conformation test, the warpage deflection shows a lowest value for each type of gate. Therefore, the objective to make the lower deflection of warpage was satisfied. From ANOVA analysis, for single gate, the highest factor that contributes towards warpage is melt temperature (46.73%), followed by packing pressure (25.06%) and the least contribution is mold temperature (10.14%). Moreover, from observation, the most significant results tested on double gate are mold temperature (35.79%), and packing pressure being the least (11.18%). When results of single gate and double gates were compared, its shows that the warpage value for double gates had a better result. Therefore, the warpage problem can be improved when double gate was used.

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