EFFECT OF PROCESSING PARAMETERS ON WARPAGE OF INJECTION MOLDED PARTS USING TAGUCHI METHOD

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ABSTRACT

There are lots of plastic components produced by using injection molding process. The plastic parts are used in the most of practical applications such as electronics, automotive, medical, aerospace, and construction areas. The plastic product is normally lowed its quality by some defects appeared on the molded part such as warpage and shrinkage. The injection molding process is controlled via adjusting the injecting process parameters to get the high quality of final parts such as minimizing the warpage of product. This paper demonstrates the design of experiment method (DOF) with Taguchi technique to investigate the effect of process parameters on warpage of injection molded parts during injection molding process. By Taguchi method, the orthogonal array is designed to optimize warpage via controlling the influencing factors of melt temperature, mold-open time, and cycle time. ANOVA analysis is used to figure out the most effect of the parameters on the warpage. The results show that the melt temperature has highest effect on the warpage, the second position is cycle time, and third factor of mold-open time has smallest effect on the warpage.

Keywords: *ANOVA; Injection molding; Optimization; Taguchi method; Warpage.*

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NOMENCLATURE

°C: Degree Celsius
s: Second
MPa: Megapascal
g: Gram

1. INTRODUCTION

Injection molding is one of the most common method used to make plastic components [1]. The plastic products are introduced in the most of daily applications such as, consumer goods, automotive, electronics, aerospace, medical, and construction areas. The injection molding process includes some basic steps of filling phase, packing phase, and cooling stage. There are some defects occurred during plastic molding such as warpage, short shot, air traps, and shrinkage. The injection molding process (IMP) is monitored through controlling the injecting process parameters such as melt temperature, mold-open time, and cycle time to improve the quality of plastic product. Computer-aided engineering (CAE) is the effective method used to verify reasons that effect on the quality of final molded parts. There are many research group focused to apply the CAE technique in plastic injection molding manufacturing such as using simulation tool to adjust the plastic flow into the cavity and the ratio of plastic dynamic viscosity during injection molding process [2], reducing the shrinkage and the warpage of polymer product via using Autodesk Moldflow software [3], enhancing the pressure curve of cavity deformation in injection molding process [4], and using simulation method to optimize the cooling system of the plastic mold [5]. Taguchi method is one of the most effective techniques used to optimize process parameters of manufacturing like injection molding process. Many researches have been developed Taguchi method for controlling the manufacturing process to get high quality of product such as using Taguchi method to optimize the control parameters of injection molding process [6], applying Taguchi technique to optimize the shrinkage of plastic product during injection molding [7], using Taguchi method in optimization process of injection molding factors for auto-lock product [8], and applying Taguchi solution to get the optimal process parameters of injection molding process [9]. This paper demonstrates the design of experiment method (DOF) with Taguchi technique to investigate the effect of process parameters on warpage of injection molded parts during injection molding process. By Taguchi method, the orthogonal array is designed to optimize warpage via controlling the influencing factors of melt temperature, mold-open time, and cycle time. ANOVA analysis is used to figure out the most effect of the parameters on the warpage. The results show that the melt temperature has highest effect on the warpage, the second position is cycle time, and third factor of mold-open time has smallest effect on the warpage.

2. MODEL PREPARATION

2.1. Sample description and material

Fig. 1 shows the image of the product designed in NX software. Fig. 1(a) shows the front view of the product. Fig. 1(b) shows the top view of the product. Fig. 1(c) shows the 3D view of the product. The sample is made of acrylonitrile butadiene styrene (ABS) with the trade name of TFX-210 from Monsanto Kasei manufacturer. Table 1 shows the mechanical properties of the plastic material.

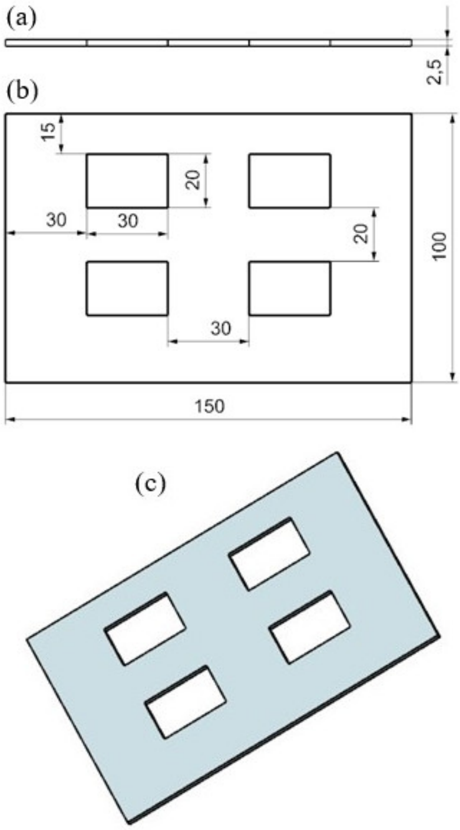

Fig. 1. The images of the product designed in NX software: (a) The front view of the product; (b) The top view of the product; (c) The 3D view of the product

Table 1. The mechanical properties of ABS material

Items	Unit	Value
Elastic modulus	MPa	2760
Shear modulus	MPa	992.8
Poisson's ratio	-	0.39
Coefficient of thermal expansion	1/ºC	9.49e-05
Transition temperature	ºC	100
Melt density	g/cm^3	0.97453

2.2. Processing analysis

Fig. 2 shows the injection mold that is designed for molding the plastic product. The figure shows the basic information for molding process analysis including the molding part, the gate location, and the cooling channel. The mold was designed with a feed runner of 8mm in diameter and a gate runner of 3mm in diameter. The cooling channel was designed with the cross section of circular type and the diameter of 10mm.

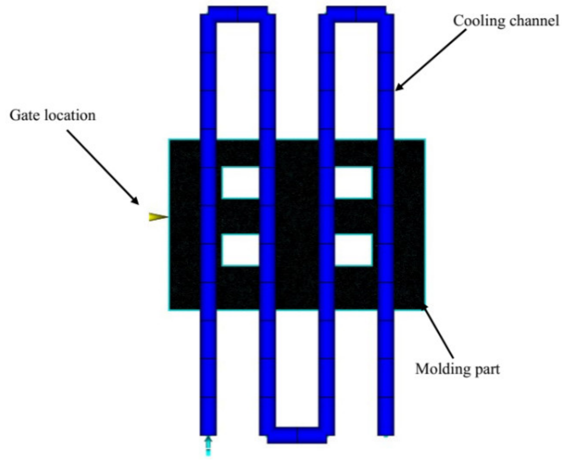

Fig. 2. The injection mold that is designed for molding the plastic product

Table 2 shows the molding conditions that was used in this study to optimize the warpage defect of the molded sample.

Table 2. The molding conditions for optimization

Items	Unit	Value
Melt temperature	ºC	210 - 250
Mold-open time	s	4 - 6
Cycle time	s	24 - 36

3. RESULTS AND DISCUSSION

3.1. Optimization with Taguchi method

Table 3 shows the processing parameters used to optimize the warpage of product. The processing parameters are arranged in three levels following Taguchi method. The main factors are used to optimize the warpage in the Taguchi method including the melt temperature (A), the mold-open time (B), and the cycle time (C).

Table 3. The parameters and the levels

Parameters	Levels		
	1	2	3
Melt temperature (A)	210	230	250
Mold-open time (B)	4	5	6
Cycle time (C)	24	30	36

Table 4 shows the 9 experiments arranged in the orthogonal array of L9 following Taguchi method. The table shows number of the experiments corresponding the parameters. For example, No. 1 is the first experiment in the orthogonal array with the melt temperature of 210ºC, the mold-open time of 4 seconds, and the cycle time of 24 seconds, respectively.

Table 4. The L9 orthogonal array

No.	A	B	C
1	1	1	1
2	1	2	2

3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

The experiments of injection molding process were done based on the arrangement of the above orthogonal matrix. The maximum warpages of products were determined by using the simulation tool of Moldflow software. Fig. 3, for example, shows the warpage analysis result of one experiment performed by using Moldflow software. The maximum warpage analysis values of the total experiments are filled in the Table 5. The signal-to-nose ratios (S/N) were calculated for each experiment with the mean of the smaller of the warpage as the better. The total S/N values were calculated following below formula (1) and filled in the Table 6.

$$S/N = -\log\left[\frac{1}{n}\sum y^2\right] \quad (1)$$

Where:

S/N is signal-to-noise ratio

n is the number of the experiments

y is value of the experiment.

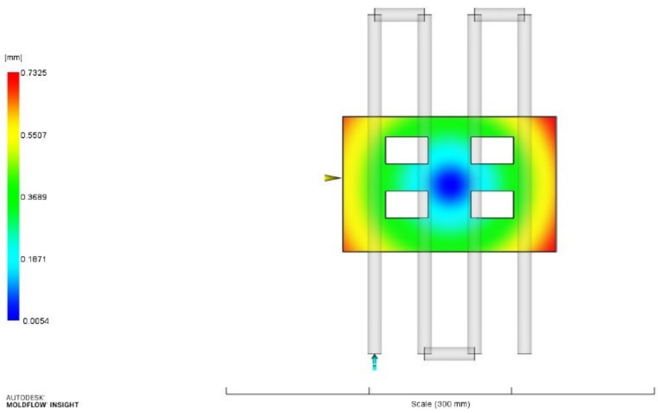

Fig. 3. The warpage analysis result performed by using Moldflow software

Table 5. The values of the maximum warpages and S/N ratios

No.	Warpage (mm)	S/N
1	0.732	2.70978
2	0.729	2.74545
3	0.728	2.75737
4	0.793	2.01454
5	0.791	2.03647
6	0.794	2.00359
7	0.824	1.68146
8	0.835	1.56627
9	0.833	1.58710

Fig. 4 shows the signal-to-noise ratio variation that is analyzed by using Minitab software. The optimal parameters are selected by analysis with the criteria of minimum warpage or smaller warpage as better. The results show that the optimal injection molding parameters are the melt temperature of 210°C, the mold-open time of 4 seconds, and cycle time of 36 seconds.

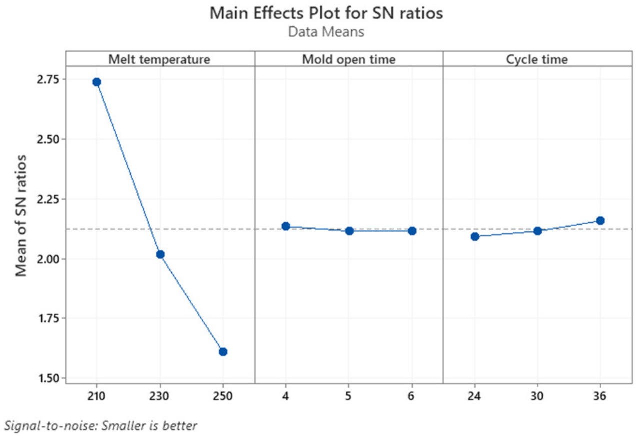

Fig. 4. The signal-to-noise ratio variation

Table 6 shows the analysis of variance of the signal-to-noise ratios. The ANOVA analysis was done to investigate the factor that has highest effect on the warpage of the product. The table shows that the melt temperature and the mold-open time have significant effect on the warpage because its P values are less than 0.05. The mold-open time has insignificant effect on the warpage of product because its P value is higher than 0.05.

Table 6. The analysis of variance

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Melt temperature	2	0.015614	0.015614	0.007807	867.44	0.001
Mold open time	2	0.000008	0.000008	0.000004	0.44	0.692
Cycle time	2	0.000056	0.000056	0.000028	3.11	0.243
Residual Error	2	0.000018	0.000018	0.000009		
Total	8	0.015696				

3.2. Validation test

The experiment test was done with the optimal processing parameter after analyzing the values via ANOVA and Taguchi method with the optimal factors of A1-B1-C3 by using Moldflow software. The maximum warpage recorded about 0.728mm from simulation with the optimal parameters. The optimal predict value is about 0.725mm produced by Minitab software. This means that the error of optimal results are very small with only 0.41% in comparison between the optimal predict value and the optimal experiment value.

4. CONCLUSIONS

In this study, a plastic panel was put onto simulation for injection molding process. The processing parameters were arranged in the experimental plan by using Taguchi method to investigate the optimal injection molding condition to minimize the warpage defect of the final product. The ANOVA analysis was conducted to examine that which factor has highest effect on the warpage. The results show that the optimal molding parameters set are the A1-B1-C3. The results also show that the melt temperature and the mold-open time have significant effect on the warpage. The mold-open time has insignificant effect on the warpage of product. The research hopes that the results are applied in the real manufacturing of plastic product by injection molding to reduce defects of final product.

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