An Optimization of Plastic Injection Molding Parameters Using Taguchi Optimization Method

Radhwan Hussin, Rozaimi Mohd Saad, Razaidi Hussin, Mohd Syedi Imran Mohd Dawi

Abstract — *During producing a product using injection molding process, various defects such as warpage, weld lines, shrinkage and sik mark can be occured, optimal setting up of injection molding process is very important to reduce the defect and controlling the quality defect of the injection molded product. The purpose of this paper is to minimizing warpage defect on Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) thermoplastic and simulates the injection molding process using Moldflow Plastic Insight software (MPI). The approach was based on Taguchi's Method and Analysis of Variance (ANOVA) has been implemented to analyze and optimize the processing parameters such as mold temperature, melt temperature, packing time, packing pressure, cooling time, cooling temperature, ambient temperature and runner size***.**

Index Terms — Injection molding, Taguchi's method, Warpage.

I. INTRODUCTION

Injection Molding is one of the techniques used in producing plastic and this process actually is the most practical and cost effective to produce plastic products [1]. It is a very complex process due to various parameter that must be considered. Product must be design "Fit for purpose", which means that product should be produced for a maximum quality at a minimal cost [2]. This study is to determine the significant of molding parameters and produced the best parameter setting for the product. Optimization is the procedure to make a systems or design functional as possible, especially the mathematical techniques involved. Optimization of molding parameter is to make improvement about the molding parameter that effect to warpage in injection molding. Warpage is one of common effects on molded parts after taken out from an injection molding process. It is important issue to predict the warpage issue before run manufacturing process. Based on literature review, normally most of researcher use parameter mold temperature, melt temperature, packing time, packing pressure, cooling time, cooling temperature, ambient temperature, runner size, runner type, gate location and etc to ensure the quality of plastic being produced. However, [3]-[7] stated that the significant parameter effect on warpage defect in injection molding process was melt temperature, mold temperature, packing time, packing pressure, cooling temperature and gate location.

In order to produce the optimized setting for producing plastic, they are various tools and technique of optimization. In this project, we focused on Design of Experiment (DOE). DOE is the most powerful quality improvement techniques to reduce process variation, enhance process effectiveness and process capability [8]. A similar study on DOE done by [8], and present some fundamental and critical differences between taguchi and classical methods of design of experiment. According to [8], "The choice of a DOE strategy (Taguchi or classical DOE) depends a great deal on the degree of optimization required, resolution required, time and cost constraints, nature of the problem" and they are illustrates the power of Taguchi approach to DOE. This concurred with [1], [3]-[5], [7], [9]-[14] of the power of using taguchi approach because this method is a robust design, and they also apply the same method in optimization parameters of injection molding plastic part.

II. SCOPE AND LIMITATIONS

The scope and limitation consist of:

i. Only defect warpage will be observed for the optimized parameters.
ii. Parameters to be studied include mold temperature, melt temperature, packing time, packing pressure, cooling time, cooling temperature, and runner size.
iii. Moldflow plastics insight software and Design of experiment will be employed to analysis and optimization.

III. TOOL AND MATERIAL

Moldflow Plastic Insight software (MPI) is used in simulation to observe the warpage defect on the plastic part. The simulation processes start with the development of the model by using Computer Aided Design (CAD). Shin guard is being selected for this project because it easily deform the warpage effect. Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) thermoplastic material was used for this experiment. The material properties for PC/ABS are shown in table 1 with different manufacture group. There are various materials are used in this experiment manufactured from Mitsubishi group (1), SABIC Innovative Plastics US, LLC (2), and SABIC Innovative Plastics B.V. (3) in order to get the robust result.

TABLE I
THE PHYSICAL PROPERTIES OF PC/ABC

Group Manufacture	**1**	**2**	**3**
Country Origin	Japan	USA	Europe
Material structure		Amorphous	
Melt density (g/cm^3)	1.0917	1.0141	0.97681
Solid density (g/cm^3)	1.2054	1.1429	1.1161
Elastic modulus (Mpa)		2780	
Poisson's ratio		0.4	
Shear modulus (Mpa)		992.9	

Step involved in methodology for this study start from 3D modeling until confirmation run are shows in Fig.1.

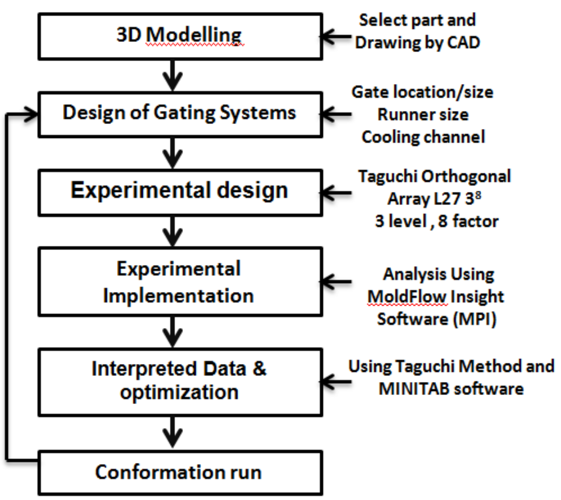

Fig.1. Steps involved in the methodology

A. Design of Product

A shin guard plastic part shows in Fig.2 was prepared using UNIGRAPHIC NX7.5. The model was design has a different thickness 1.5 mm at the both side and 3 mm at the middle. The ribs were located at this model to produce a minimum defect on warpage.

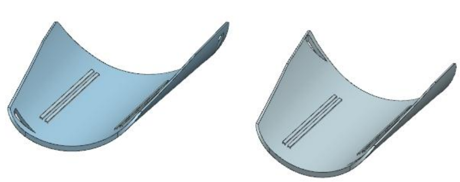

Fig.2. Design of product.

B. Gating system design

Plastic Insight software (MPI) used to design gating system shows in Fig.3 and simulate the injection molding process after finish setup the parameters using for this simulation.

i. The gate location results rates each place on the model for its suitability for an injection location.
ii. Simple runners system was used for this research is side gate. The dimension for the runners system is circular size with 5mm, 6.5mm and 8mm.
iii. Proper cooling system was designed to assist the whole mold system and the diameter for each channel is 10 mm, and the space in between channels is 25 mm.

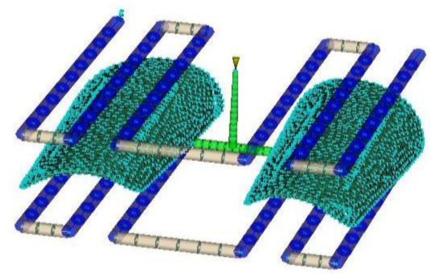

Fig.3. Gating system design

C. Run simulation

Several parameters is take into consideration in which the injection location, cavity layout, cooling circuit design, flow rate setting, injection pressure setting and the packing pressure setting, run the analysis check. Fig.4 shows the part after run simulation.

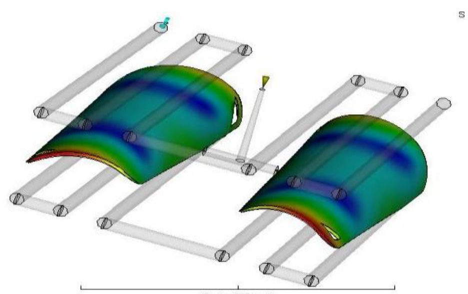

Fig.4. Run simulation

D. Taguchi's experimental method

Taguchi method is an effective method targeted at quality improvement for product development and it was used in designing of our experiments. There are eight factors identified to control the injection process; mold temperature (A), melt temperature (B), packing time (C), packing pressure (D), cooling time (E), cooling temperature (F), ambient temperature (G), and Runner size (H). Each factor consists of three levels where an orthogonal array L27 (38) was used to suit the inputs and all parameters have been identified. According to Taguchi, two major tools were employed to achieve any quality goal or any robust design. Taguchi uses the S/N ratio to measure quality characteristic deviating from the desired value. The S/N ratio characteristics can be divided into three categories: the-nominal-the-best, the smaller-the-better, and the-larger-the-better. Selection of which OA to use mostly depends on these items in order of numbers of factors and interactions of interest, number of levels for the factors of interest, and the desired experimental resolutions or cost limitations. The results that were considered in Taguchi method is warpage. Table 2 and Table 3 shows the parameters and Taguchi Orthogonal Array which are used for analyzed.

TABLE 2
THE PROCESS PARAMETERS AND THEIR LEVELS

Experimental Factors	Experimental Level 1	2	3
A: Mold Temperature (^{0}C)	60	80	100
B: Melt Temperature (^{0}C)	240	260	280
C: Packing Time (Sec)	8	10	12
D: Packing Pressure (MPa)	140	150	160
E: Cooling Time (Sec)	17	21	25
F:Cooling Temperature (^{0}C)	22	24	30
G: Ambient Temperature (^{0}C)	20	27	35
H: Runner Size (mm)	5	6.5	8

TABLE 3
THE ORTHOGONAL ARRAY L27 (3^8)

Trial No	A	B	C	D	E	F	G	H
1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2
3	1	1	1	1	3	3	3	3
4	1	2	2	2	1	1	1	2
5	1	2	2	2	2	2	2	3
6	1	2	2	2	3	3	3	1
7	1	3	3	3	1	1	1	3
8	1	3	3	3	2	2	2	1
9	1	3	3	3	3	3	3	2
10	2	1	2	3	1	2	3	1
11	2	1	2	3	2	3	1	2
12	2	1	2	3	3	1	2	3
13	2	2	3	1	1	2	3	2
14	2	2	3	1	2	3	1	3
15	2	2	3	1	3	1	2	1
16	2	3	1	2	1	2	3	3
17	2	3	1	2	2	3	1	1
18	2	3	1	2	3	1	2	2
19	3	1	3	2	1	3	2	1
20	3	1	3	2	2	1	3	2
21	3	1	3	2	3	2	1	3
22	3	2	1	3	1	3	2	2
23	3	2	1	3	2	1	3	3
24	3	2	1	3	3	2	1	1
25	3	3	2	1	1	3	2	3
26	3	3	2	1	2	1	3	1
27	3	3	2	1	3	2	1	2

IV. RESULTS AND DISCUSSIONS

According to the DOE, twenty seven experiments for each material of manufacture group were conducted and all the warpage data presented in Table 4. S/N (signal-to-noise) ratio is one of the measurement indexes for quality characteristics. Data points were analyzed using the "smaller-the-better approach" due to this research is focused on minimize warpage in injection molding process within optimal process parameters. As a result the smaller-the-better quality characteristic is selected for this study. The S/N ratio was calculated using equations (1) and MSD using equation (2). MSD is the mean square deviation, y represents the value of warpage and n is the number of tests in one trial. Response Table for signal to noise ratio was constructed in Table 5.

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

$$\text{Where } MSD = \frac{1}{2} \sum_{i=1}^{n} yi^2 \quad \text{----------} (2)$$

Based on the response table of S/N ratio at table 5, constructed S/N ratio graphs can be seen in Fig.5.

TABLE 4
SUMMARY OF RESULTS

RUN	Warpage (mm) 1	2	3	Mean	MSD	S/N Ratio
1	1.015	1.213	1.060	1.096	3.625	-0.822
2	0.939	1.137	0.984	1.020	3.144	-0.204
3	0.868	1.066	0.913	0.949	2.722	0.422
4	0.863	1.061	0.908	0.944	2.692	0.470
5	0.882	1.080	0.927	0.963	2.801	0.298
6	0.872	1.070	0.917	0.953	2.748	0.381
7	0.808	1.006	0.853	0.889	2.393	0.983
8	0.895	1.093	0.940	0.976	2.879	0.178
9	0.808	1.006	0.853	0.889	2.391	0.985
10	0.940	1.138	0.985	1.021	3.148	-0.209
11	0.930	1.128	0.975	1.011	3.085	-0.121
12	0.903	1.101	0.948	0.984	2.925	0.111
13	0.857	1.055	0.902	0.938	2.661	0.521
14	0.859	1.057	0.904	0.940	2.671	0.504
15	0.953	1.151	0.998	1.034	3.231	-0.323
16	0.798	0.996	0.843	0.879	2.341	1.078
17	0.883	1.081	0.928	0.964	2.809	0.286
18	0.875	1.073	0.920	0.956	2.760	0.361
19	0.916	1.114	0.961	0.997	3.003	-0.004
20	0.919	1.117	0.964	1.000	3.022	-0.032
21	0.881	1.079	0.926	0.962	2.795	0.307
22	0.874	1.072	0.919	0.955	2.758	0.365
23	0.850	1.048	0.895	0.931	2.621	0.587
24	0.885	1.083	0.930	0.966	2.819	0.270
25	0.765	0.963	0.810	0.846	2.169	1.409
26	0.729	0.927	0.774	0.810	1.991	1.481
27	0.854	1.052	0.899	0.935	2.646	0.545
		TOTAL		**25.806**	**74.852**	**10.126**
		MEAN		**0.956**	**2.772**	**0.375**

TABLE 5
RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS USING SMALLER-THE-BETTER

Level	1	2	3	Delta	Rank
A	0.29900	0.24525	0.58085	0.33560	4
B	-0.06139	0.34142	0.84508	0.90647	1
C	0.26039	0.51819	0.34653	0.25780	5
D	0.42588	0.34951	0.34972	0.07638	8
E	0.42111	0.36413	0.33987	0.08124	7
F	0.34622	0.30926	0.46962	0.16036	6
G	0.26906	0.24349	0.61256	0.36907	3
H	0.17084	0.32108	0.63319	0.46235	2

Fig.5 shows the S/N ratio response diagram for warpage. Based on this figure, it can be easily to identify the optimal parameters to minimize warpage. Selecting the highest value among each point could identify these optimization levels. The optimum setting for our research is presented in Table 6. The highest data was belonging to melt temperature. It clearly can be concluded that melt temperature was the most significant parameter that affect the value of warpage.

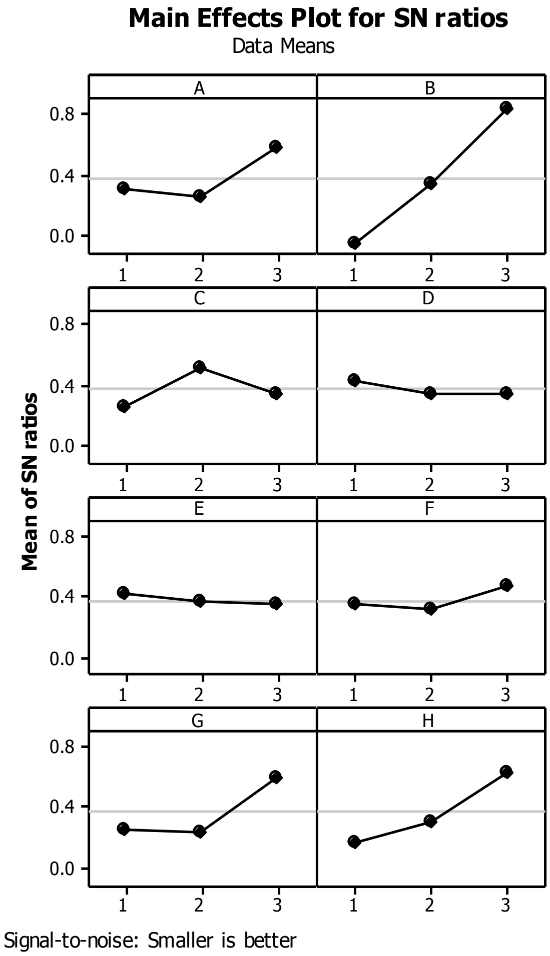

Fig.5. response diagram of S/N ratio

TABLE 6
OPTIMUM SETTING TABLE

MEAN	A(2)	B(1)	C(1)	D(3)	E(3)	F(2)	G(2)	H(1)
S/N	A(3)	B(3)	C(2)	D(1)	E(1)	F(3)	G(3)	H(3)
Rank	4	1	5	8	7	6	3	2

Based on Table 7, the optimum setting result was produced by a combination of A3, B3, C2, D1, E1, F3, G3 and H3 and there are mold temperature 100 ^{0}C, melt temperature 280 ^{0}C, packing pressure 140 MPa, packing time 10 s, cooling time 17 s, cooling temperature 30 ^{0}C, ambient temperature 35 ^{0}C and runner size 8mm.

TABLE 7
RECOMMENDED SETTING

FACTOR	RECOMMENDED SETTING
Mold Temperatue(A)	100°C
Melt Temperature(B)	280°C
Packing time (C)	10 Sec
Packing Pressure(D)	140 MPa
Cooling time(E)	17 Sec
Cooling temperature(F)	30°C
Ambient temperature(G)	35°C
Runner size(H)	8 mm

Confirmation experiment

Using the response table S/N ratio, the confirmation experiment S/N ratio was estimated based on the calculations is shown as follows:

Z = Z bar + (B3-Z) + (H3-Z) + (G3-Z) + (A3-Z) + (C2-Z) + (F3-Z) + (E1-Z) + (D1-Z)

= 0.43 + 0.42 + 0.21 + 0.18+ 0.15 + 0.08 + 0.03 + 0.01 + 0.00

= 1.5

Using this optimum setting of factors in simulation, it has produced a minimum warpage decrease 12% shows in Table 8.

TABLE 8
RESULT OF CONFIRMATION

RUN	Warpage in mm 1	2	3	Mean
1	0.635	0.833	0.682	0.712

= (0.81 – 0.712 / 0.81) x 100

= 12.1 %

Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) is used to determine their percentage of affecting parameters on the warpage. Analysis of variance ANOVA will compute the quantities such as sum of squares (S), degree of freedom (*f*), F-statistic (F), Mean Square (MS) and percentage (P). The results were summarized in table 9.

The $F_{0.05,2,26}$ =3.37 for a level of significant parameter that's equal to 0.05 (or 95% confidence level). Cooling time (E) [$F_{statistics}$ =0.58 < $F_{0.05,2,26}$ = 3.37] and Cooling temperature (F) [$F_{statistics}$ =2.35 < $F_{0.05,2,26}$ = 3.37] does not give a significant effect to the warpage. While mold temperature (A) [$F_{statistics}$ =10.83 > $F_{0.05,2,26}$ = 3.37] , melt temperature (B) [$F_{statistics}$ =68.76 > $F_{0.05,2,26}$ = 3.37], packing time (C) [$F_{statistics}$

$=5.74 > F_{0.05,2,26} = 3.37$], packing pressure (D) [$F_{statistics} =5.84 > F_{0.05,2,26} = 3.37$], ambient temperature (G) [$F_{statistics} =14.2 > F_{0.05,2,26} = 3.37$], and runner size (H) [$F_{statistics} =18.54 > F_{0.05,2,26} = 3.37$] give us a significant effect to the warpage, with mold temperature (B) giving the highest significant level.

The melt temperature (B) contributes the most percentage values which is 54.22% follow by runner size (G) 14.62%, ambient temperature (G) 11.17%, mold temperature (A) 8.54%, packing pressure (D) 4.61%, and packing time (C) 4.53% as the influence factor for warpage defect. Cooling temperature (F) contributed 1.85% and lastly cooling time (E) only contributed 0.46% and it will be said that the cooling temperature and cooling time is not the significant factor for the warpage defect in this study.

TABLE 9
ANOVA TABLE

Source	S	*f*	MS	F	P %
A	0.022	2	0.011	10.83	8.54
B	0.138	2	0.069	68.76	54.22
C	0.011	2	0.006	5.74	4.53
D	0.012	2	0.006	5.84	4.61
E	0.001	2	0.001	0.58	0.46
F	0.005	2	0.002	2.35	1.85
G	0.028	2	0.014	14.2	11.17
H	0.037	2	0.019	18.54	14.62
Error	0.010	10	0.001		
Total	0.246	26			

V. CONCLUSION

Injection molding produced many plastic products nowadays and some factor must be determined in order to minimize the defect of injection molding plastic part. In this study, warpage for PC/ABS material shows the different values when various of parameter level are used for this computer simulation (mold flow plastic insight software). Based on this expriment, it may be concluded that Taguchi method was successfully help to solve the problem to optimize the parameters within each levels. Computer simulation and taguchi method provides an efficient and economical way of replacing the traditional method of trial and error, for engineering design and analysis.

The conclusions of the study are as follows:

iv. Melt temperature (B) contributes the most significant which is 54.22% followed respectively by Runner size (G) 14.62%, ambient temperature (G) 11.17%, mold temperature (A) 8.54%, packing pressure (D) 4.61%, and packing time (C) 4.53% as the influence factor for warpage defect.

v. Cooling temperature (F) and cooling time (E) only contributed 1.85% and 0.46%, it is not the significant factor for the warpage defect in this study.

vi. Mold temperature 100 ^{0}C, melt temperature 280 ^{0}C, packing pressure 140 MPa, packing time 10 s, cooling time 17s, cooling temperature 30 ^{0}C, ambient temperature 35 ^{0}C and runner size 8mm is using as the best parameter for minimum warpage.
12% decrease of warpage defect after run conformation using this parameter.

vii. Selection of parameter and suitable range between each level is important to give more effect in this study.

viii. The different manufacture companies producing same type of material give a little different values of result.

By doing this study, it will ensure manufacturers to start production with a better starting data and furthermore could reduce time consume and material production.

Future works

To get a better result, it is suggest running another injection molding software and comparing result between Moldflow Plastic Insight software. Try to find more parameters with more of levels to get results more accurately when do the optimization. Adding more defect of plastics injection to be study and find best filling time.

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