A Comparative Study of Mould Base Tool Materials in Plastic Injection Moulding to Improve Cycle Time and Warpage Using Statistical Method

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ABSTRACT

In the injection molding process, productivity is measured in terms of the molding cycle time and quality is measured as the extent of warpage of moulded parts. In this study, Computer-Aided Engineering was employed through Moldex 3D simulation software to simulate the injection moulding process. The processing parameters such as melt temperature, ejection temperature, mould temperature, injection pressure, packing pressure, injection time, packing time and including the mould tool material were selected to determine the cycle time and warpage of the simulated part. By using Taguchi Method orthogonal arrays, Signal-to-Noise (S/N) ratio and Analysis of Variance (ANOVA), the simulation result of the moulding cycle time and warpage of Tool Steel (P-20), Aluminum Alloy (QC-10), and Copper Alloy (Be-Cu C18000) insert with conventional cooling channels were analyzed. The result of Aluminum Alloy (QC-10) insert was in a good agreement with the result of the Signal-to-Noise (S/N) whereby Aluminum Alloy (QC-10) has been selected as the best setting of combination for cycle time and warpage. The result also shows that by percentage contribution in ANOVA, ejection temperature,mould material and injection pressure has been identified to be the most significant factors in affecting the cycle time because its P value is less than 0.05. Whereby the ejection temperature contributes the most which is 49.87%, followed by mould material 29.22% and injection pressure 11.38%. While for warpage defect, melt temperature, ejection temperature, injection pressure and packing time were the most significant factor on warpage based on its P value is less than 0.05. The factor of melt temperature has the most percentage of contributions which is

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24.69%, followed by ejection temperature 20.71%, injection pressure 18.01% and packing time 12.72%.

Keywords: *Cycle Time, Warpage, Injection Moulding, Taguchi, Statistical Method.*

Introduction

Plastic injection moulding (PIM) is a major manufacturing approach in the plastic industry. PIM is basically a repetitive and cyclical process in which melted plastic at high pressure is injected into a mould cavity, cooled and held under pressure until it can be ejected, duplicating the shape of the mould cavity[1]–[4]. In the meanwhile the pressure to manufacture PIM tools at minimum cost and the demand to get products on market more rapidly created several advantages in aluminum mould that meet these requirements. With its capability to transfer heat from the mould five times greater than steel specifically resulted the plastic material flows longer distances with minimal injection pressure, moulds fill more efficiently and parts have minimal warp and better dimensional constancy when compared to steel [5]. It went on to say these tools produced higher quality products having cycle times that were 25 to 40% less than the steel moulds. An additional advantage is faster machining times, which can reduce the mould-build time by 10-15% in some instances [5]. Quality and productivity were the important target in the injection molding process, whereby one of the quality factor is measured from the magnitude of warpage of moulded parts and productivity is measured in expressions of the moulding cycle time**.**

Dimensional stability or others may denote it to deflection or warpage is the difference between the nominal position and actual moulded position. The warpage problem is a common effect on the moulded product after removed from the plastic injection process [6,7]. In relations of dimensional stability, the lesser the deflection, the better the quality of the moulded part. The occurrence of warpage is highly influenced from the product design, mould design and machine parameter setting [3]. Therefore the preliminary prediction of warpage is essential before performing the plastic injection process. Finite Element software such as CAD Mould, Autodesk Moldflow Insight (AMI) and Moldex on theoretical simulation as well as experimental results were often conducted by researchers and engineers to forecast possible causes of warpage. By applying Statistical Method such as Taguchi, Respond surface, Factorial design method for the simulation or experimenalt work, the optimization on the occurrence and the most significant factor which caused warpage can be identified. On top of that, this method were used to achieve the optimum moulding cycle time.

N. A. Shuaib et al. [8] applied Taguchi method in his study on mould surface temperature, core and cavity temperature and injection moulding parameters in minimizing warpage for thin shallow plate parts and found that by assigning core and cavity temperature reduced the warpage in Z deflection by 79.9%.

Sri Srinivasa Muktevi [9] have conducted a research work on different mould material such as Steel, Aluminum and Beryllium Copper to investigate the effect of mould material tool on the quality and cycle time and found that the Melt temperature proved to be especially important in the warpage occurrence and the mould material and mould temperature demonstrated to be significant in relations of cycle time and heat removal from the part.

Z. Shayfull et al. [10] implemented Taguchi Method to establish the ideal value of injection moulding parameters and AMI software is used to simulate the injection moulding process. The temperature differences on cavity and core plates were measured in simulation and the experimental displays that the differences mould temperature aids to minimize the warpage.

Jacques [11] have conducted a simulation on the thermal warpage caused from inadequate cooling on a plate, and it is found that the warpage issue originates from the bending moment cause to the asymmetrical stress distribution over the plastic parts. The thinnest spot on moulded parts is usually the greatest pretentious area of warpage as a result of its relatively smaller second moment of area in bending.

Matsuoka et al. [12] also studied warpage by conducting simulation and experimental studies exposed that the orientation of material flow has a significant effect on shear stress, shrinkages, warpage and mechanical of the moulded plastic parts. As observed by Babur Ozcelik and T. Erzurumlu [13] in the experiment of thin shell PC/ ABS material for different thickness value discovered that the packing pressure was the most significant parameter contributing to warpage. This is also agreed by Hasan Oktem et al. that conducted an investigation on the effect of packing pressure on the thin shell products that contribute to warpage.

S.M. Nasir et al. [14] investigated the relationship between warpage and the various process parameters, namely mould temperature, melt temperature, injection time, packing pressure and packing time. PC, PC/ABS and ABS material were used in this work and the analysis that has been performed by Taguchi Analysis and extended with ANOVA optimization methods. The results for both methods used have been analyzed. From all the experiments that have been conducted, packing time is found the most significant factor that contributes towards warpage occurrence regardless of materials used. Therefore, types of material used are not considered significant.

There have been numerous articles published investigating the relation of the product design, mould design and machine parameter setting regarding the warpage and cycle time using statistical methods, but there is little specific information available to establish the influence of mould tool material and how it improves the injection mould process. In this study, AMI software is used to identify the influence of mould tool material and best parameter setting that contributes to improve the quality and productivity in an injection molding process.

Physical and Mathematical Modeling

In the injection moulding process, conduction heat transfer occurs in the mould material and drives through the boundary of plastic material and mould material. Referring to Joseph Fourier, the French mathematical physicist, the energy transfer can be described by mathematical Equations (1) [15] , as follows,

$$Q_c = KA\frac{\Delta T}{L} \tag{1}$$

Where, Q_C = conduction heat transfer energy K = thermal conductivity of the material or medium, A = area of the core or cavity in contact with the plastic material, ΔT= temperature difference between two mediums (hot polymer material and coolant), L = distance between two mediums.

Convection heat transfer occurs in the cooling interface where heat energy originates through the boundary of the mould material and cooling channels. Some convection heat transfer also arises on the mould surface, which is normally less significant [16]. Referring to Newton's law of cooling, Total heat transfer by convection in the cooling channel can be described by the Equation (2) [15];

$$Q_h = hA(T_w - T_c) \tag{2}$$

Where, A= contact cooling channel surface area with the flowing fluid. T_w = temperature of the cooling channel wall, T_C = coolant temperature. The values of T_w and T_C are not constant in real situations of injection moulding process.

And finally, radiation heat transfer occurs over the moulds outer surface into the atmosphere which is also of insignificant amount and has been neglected. The total heat flow in the plastic injection moulding tool as shown in Figure 1 can be written in Equation (3). The values of L are the width and A represent the area of the parts. The values of k are the conductivity coefficient and the values of h is the convection coefficient of the different parts.

Mould Tool Material

The mould material is one of the factors that affect the quality and productivity of the product. Three types of mould material have been preferred in this simulation; Beryllium-Copper Alloy (Be-Cu C18000), Aluminum Alloy (QC-10) and Tool Steel (P-20). Detail of physical and mechanical properties of the mould materials used is presented in Table 1. Typically the mould material selection is a tradeoff of mechanical property versus thermal properties. High mechanical properties are desired as well as high thermal properties.

$$Q = h_1 A(T_{\infty 1} - T_1) = k_1\, A\,\frac{T_1 - T_2}{L_1} = k_2\, A\,\frac{T_3 - T_2}{L_2} = h_2 A(T_3 - T_{\infty 2}) \qquad (3)$$

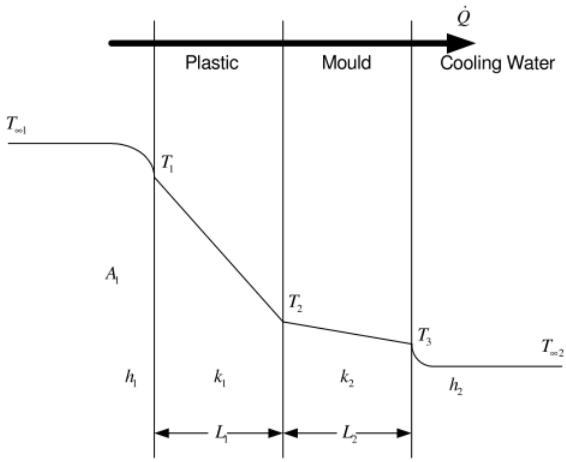

Figure 1: Heat flow in the plastic injection moulding tool

Unfortunately, as can be seen in Table 1, typical mould materials such as Beryllium-Copper, aluminum and steel do not meet all the requirements simultaneously. A Steel typically has high mechanical properties whilst low thermal properties and Beryllium-Copper and aluminum typically have high thermal properties but low mechanical properties.

Part, Feed System and Cooling Channel Design

In the design stage, the selection of feeding system is strongly dependent on the product design, type of mould and the number of cavities required in the mould. Usually for two-plate mould, the locations of gates are on the side of the component and at the parting line of the product. For cosmetic finishing purpose the gate can be allocated at the surface which the gate marks are invisible to the user after the product assembly.

In this research, the part that been used by Shayfull [1], [4] in his research project, which consisted two plate mould with a submerge gating system for the Front panel housing with dimensions of 120 mm x 80 mm x 18.75 mm and 2.5 mm thickness with a volume of 27663.64 mm^3 was carefully chosen as the case study part to be analyzed. The part, as shown in Figure 2, was selected due to its curvature shape matches with the present trend of most products.

Table 1: physical and mechanical properties of mould materials

	Aluminum (QC-10)	**Copper Alloy (C18000)**	**Steel (PC-20)**
Thermal conductivity (W/m-K)	159.12	225	34.59
Coefficient of thermal	24.7	17.5	12.8
expansion (10^{-6}/°C)	70	114	205
Modulus of elasticity (GPa)	2.85	8.81	7.87
Density (g/cm^3)	150-170	94	264-331
Hardness (HB)	70-74	75	130-135
Yield strength (ksi)			

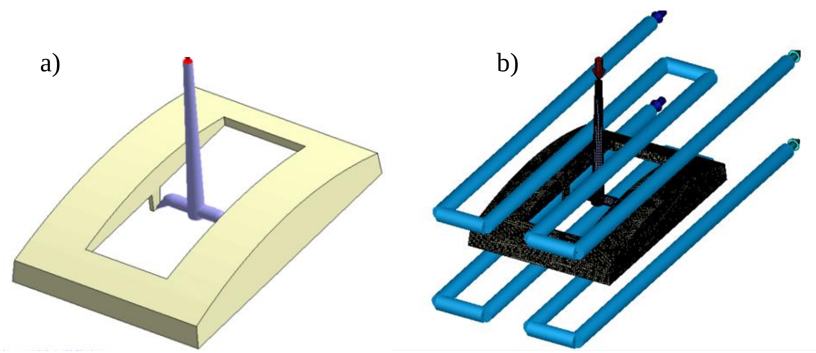

Figure 2: (a) Submerge gating system for the front panel housing (b) Cooling channel design and meshing of the parts

The part's simulation analysis is done using Moldex 3D . Regarding the meshing, the Front panel housing are divided into 411854 pieces triangular elements meshed. The mesh type employed was "3D Mesh" due to its suitability for the solid parts. Full analysis "Cool + Fill + Pack + Cool +

Warp" was set for this study in order to allow the software to compute the potential cycle time and warping under simulation process. Figure 2b shows the cooling channels and meshing of the parts.

Experimental Design

Simulation and Experimental Parameters Design

There are numerous factors influencing the plastic injection moulding process, which comprised types of plastic material complied, types of mould base material, types of core and cavity insert material, types of injection machine, the design of the product, the variety of coolant channel layout along with the selection of coolant liquid. In the simulations study the main factors to be evaluated was the types of mould base material in consort with Melt Temperature, Ejection Temperature, mould temperature, injection pressure, packing pressure, injection time, packing time to Improve Productivity (cycle time) and Quality (warpage) according the following assumptions:

- The feeding system, including the spure, runner and gate design were properly calculated by the mould designer for the specific product.
- The temperature of the environment does not have any effect on the injection process.
- Tap Water with the temperature of 25°C is the type of liquid in the cooling system.
- The coolant velocity is remaining constant at 120 mm/s.
- The conventional layout of the cooling channels with different velocity and inlet temperature, which affect cooling efficiency ubiquitously in the mould.
- The core and cavity mould insert possessed the same temperature.
- For the simulation condition setting in the Moldflow, plastic material used was the thermoplastic Acrylonitrile Butadiene Styrene (ABS) Toyolac 700-314. The properties of material are presented in Table 2

Design of Experiment

In this research work, there are eight factors identified to be the parameters, as presented in Table 3, for the designed simulations. They are the mould base material (A), mould temperature (B), melting temperature (C), ejection temperature (D), injection pressure (E), packing pressure (F), injection time (G) and packing time (E).

Taguchi Experimental Method is compelled to investigate the effect of the mould base materials and seven other injection moulding process parameters. Which factors have the significant effect or negligible effect on the Quality (warpage) and Productivity (cycle time) will be acknowledged. The S/N ratio in Taguchi will determine the significant implemented quality characteristics in engineering design situations. The S/N ratio characteristics can be categorized in three ratings; the larger the better, smaller the better, and nominal the best. Since the intention of this study is to minimize cycle time and warpage within the process parameters including the mould materials, the smaller the better characteristic is compiled.

Table 2: Physical and mechanical properties of the thermoplastics

The Physical and Mechanical Properties of ABS Toyolac 700-314	
Mould temperature (°C)	40 – 80
Melt temperature (°C)	220 - 260
Freeze temperature(°C)	129.75
Ejection temperature (°C)	109.75
Elastic modulus, E (MPa)	2700
Poisson's ratio, ν	0.38
Thermal conductivity, K (W/m°C)	0.15

Analysis of variance (ANOVA) was then employed to compute the effect of process parameters on cycle time and warpage, whereby it can conclude which process parameters are statistically significance and also the involvement of all process parameters to the output characteristic. The three levels and Orthogonal Array *Taguchi* eight factors (L27 3^8) designs are shown in Table 3 and 4 respectively.

Table 3: Control Factors and Three Levels for Simulation Variance

Factor	**Name**	**Level 1**	**Level 2**	**Level 3**
A	Mould base Material	QC-10	P-20	BeCu
B	Mould Temperature (°C)	60	70	80
C	Melting Temperature (°C)	240	250	260
D	Ejection Temperature (°C)	90	100	110
E	Injection Pressure (MPa)	100	110	120
F	Packing Pressure (MPa)	90	100	110
G	injection time (s)	1.0	2.0	3.0
H	Packing time (s)	5.5	6.5	7.5

Table 4: The Three Levels and Orthogonal Array Taguchi, Eight Factors (L27 3^8) Designs

No	Mould Material	Mould Temp. (°C)	Melt Temp. (°C)	Ejection Temp. (°C)	Enjection Pressure (Mpa)	Packing Pressure (Mpa)	Injection Time (s)	Packing time (s)
1	P20	60	240	90	100	90	1	5.5
2	P20	60	240	90	110	100	2	6.5
3	P20	60	240	90	120	110	3	7.5
4	P20	70	250	100	100	110	1	7.5
5	P20	70	250	100	110	90	2	5.5
6	P20	70	250	100	120	100	3	6.5
7	P20	80	260	110	100	100	1	6.5
8	P20	80	260	110	110	110	2	7.5
9	P20	80	260	110	120	90	3	5.5
10	Qc10	60	250	110	100	90	1	6.5
11	Qc10	60	250	110	110	100	2	7.5
12	Qc10	60	250	110	120	110	3	5.5
13	Qc10	70	260	90	100	110	1	5.5
14	Qc10	70	260	90	110	90	2	6.5
15	Qc10	70	260	90	120	100	3	7.5
16	Qc10	80	240	100	100	100	1	7.5
17	Qc10	80	240	100	110	110	2	5.5
18	Qc10	80	240	100	120	90	3	6.5
19	BeCu	60	260	100	100	90	1	7.5
20	BeCu	60	260	100	110	100	2	5.5
21	BeCu	60	260	100	120	110	3	6.5
22	BeCu	70	240	110	100	110	1	6.5
23	BeCu	70	240	110	110	90	2	7.5
24	BeCu	70	240	110	120	100	3	5.5
25	BeCu	80	250	90	100	100	1	5.5
26	BeCu	80	250	90	110	110	2	6.5
27	BeCu	80	250	90	120	90	3	7.5

Result & Discussion

In order to get the optimum parameter by using S/N ratio and the quality characteristic has chosen smaller the better regarding analysis on effect of shrinkage and warpage. Since this study is conducted to improve cycle time and warpage, smaller the better characteristic has been selected and it is expressed as in Equation (4):

$$S/N = -10LOG(MSD) \tag{4}$$

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

where MSD is the mean square deviation, *n* represents the number of tests in one trial and y indicates the observation [10]. For S/N ratios, all the factors and the interaction terms are significant at an 'α' level of 0.05.

Then the data were analyzed by analysis of variance (ANOVA) to find which parameters significantly affect the quality characteristic of samples. The most significant parameter was determined by calculating the percentages of pure sum. From the analysis the higher percentages pure sum of factor, the more affects these factors to the samples or product. The result for cycle time and warpage can be summarized as shown in Table 5. Whether S/N ratio is a positive or negative number be determined by on whether the mean-squared deviation is a number larger or smaller than 1. The examples of simulation were displayed in Figure 3(a) and 3(b).

Table 5: The result of cycle time, warpage and S/N ratio

No	Cycle time (s)	S/N Ratio	Total warpage (mm)	S/N Ratio
1	39.466	-31.9245	0.6989	3.1117
2	33.923	-30.6099	0.8197	1.7269
3	37.017	-31.3680	0.7288	2.7478
4	*34.115*	-30.6589	*0.8600*	1.3100
5	*32.172*	-30.1496	*0.8887*	1.0249
6	*34.974*	-30.8749	*0.8915*	0.9976
7	32.015	-30.1071	1.1880	-1.4963
8	31.527	-29.9737	1.0050	-0.0433
9	33.057	-30.3853	0.9920	0.0698
10	27.984	-28.9382	0.8714	1.1956
11	27.355	-28.7407	0.8838	1.0729
12	28.948	-29.2324	0.9011	0.9045
13	36.695	-31.2921	0.8892	1.0200
14	28.795	-29.1863	0.9441	0.4996
15	34.352	-30.7190	0.8217	1.7057
16	29.036	-29.2587	0.9642	0.3167
17	28.111	-28.9775	0.7757	2.2061
18	32.355	-30.1988	0.7415	2.5978
19	31.221	-29.8889	1.1620	-1.3041
20	33.486	-30.4973	0.8598	1.3121
21	32.481	-30.2326	0.8804	1.1064
22	27.403	-28.7560	0.9822	0.1560
23	26.419	-28.4383	0.9653	0.3068
24	28.602	-29.1279	0.8399	1.5154
25	38.896	-31.7981	1.0070	-0.0606
26	35.01	-30.8838	0.8025	1.9111
27	33.823	-30.5842	0.7596	2.3883

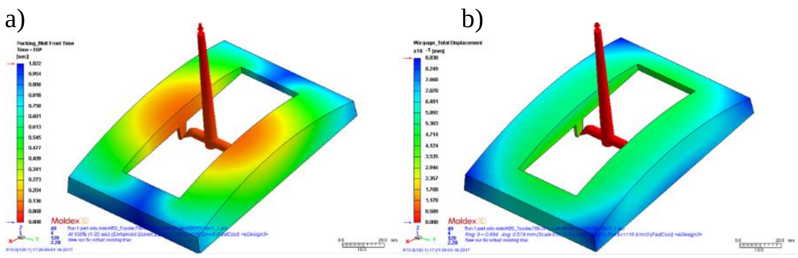

Figure 3: (a) Filling time for trial no.11 (b) Warpage for trial no.11

The response table for cycle time and warpage, shown in Table 6 and Table 7, displays the average of each S/N ratios for all levels of each factor. The table contains ranks established on Delta statistics which compare the relative magnitude of effects whereby the Delta statistic is the highest average for each factor. The ranks were determined based on the Delta value, whereas a highest Delta value was assigned to rank 1, rank 2 to the second highest, and followed. Therefore the established rank for cycle time are cycle ejection temperature (rank 1), mould material (rank 2), Injection pressure (rank 3), Melting temperature (rank 4), mould temperature (rank 5), packing pressure (rank 6), Injection time (rank 7) and packing time (rank 8).

Table 6: Response Value of S/N Ratio for Cycle Time

Level	**1**	**2**	**3**	***Delta***	***Rank***
Mould Material	-30.67	-29.62	-30.02	*1.06*	*2*
Mould Tempt	-30.16	-29.91	-30.24	*0.33*	*5*
Melt Tempt	-29.85	-30.21	-30.25	*0.4*	*4*
Ejection Temp	-30.93	-30.08	-29.03	*1.63*	*1*
Injection Pressure	-30.29	-29.72	-30.3	*0.59*	*3*
Packing Pressure	-30.3	-30.02	-30	*0.3*	*6*
Injection time	-29.95	-30.15	-30.22	*0.27*	*7*
Packing time	-30.15	-30.19	-29.97	*0.22*	*8*

Table 7: Response Value of S/N Ratio for Warping

Level	**1**	**2**	**3**	***Delta***	***Rank***
Mould Material	1.0499	1.2799	0.8146	*0.4653*	*7*
Mould Tempt	1.3193	0.9485	0.8766	*0.4427*	*8*
Melt Tempt	1.6317	1.1938	0.3189	*1.3128*	*1*
Ejection Temp	1.6317	1.063	0.409	*1.2632*	*2*
Injection Pressure	0.4721	1.113	1.5593	*1.0872*	*3*

Packing Pressure	1.2959	1.139	0.7095	*0.5865*	*5*
Injection time	1.3016	0.7453	1.0975	*0.5563*	*6*
Packing time	1.2551	1.2949	0.5944	*0.7004*	*4*

In the meanwhile, the established rank for the warpage are Melting temperature (rank 1), ejection temperature (rank 2), and Injection pressure (rank 3), packing time (rank 4), packing pressure (rank 5), Injection time (rank 6), mould material (rank 7), and Mould temperature (rank 8).

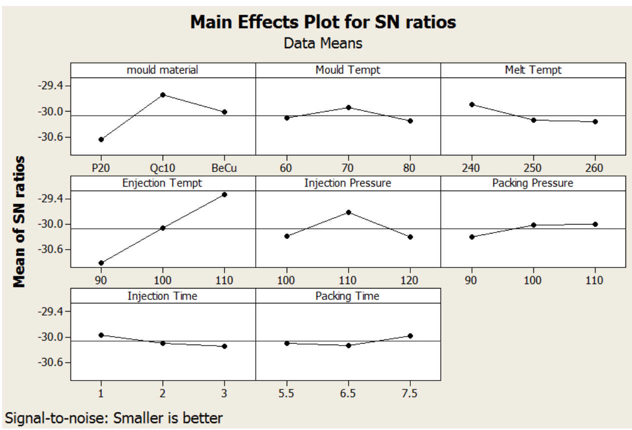

Figure 4: The main effect plot for S/N ratios for cycle time

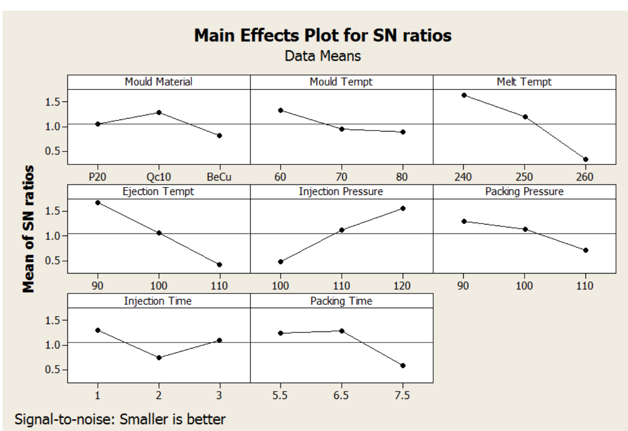

Figure 5: The main effect plot for S/N ratios for warping

The results also can be confirmed from the main effect plot for S/N ratios for cycle time and warpage in Figure 4 and Figure 5. The plot shows the grand mean at the drawn horizontal line and the response means for every single factor level. The strength of the effect of each factor can be identified on the line's slope which links the levels. High steepness line's slope indicated high power of influence of the factor.

Table 8 shows the best setting combination of all factors at a specific level. The values of the best setting combination were determined by referring to Figures 8 and 12. In these figures, the highest level value specifies the best setting for each factor.

Table 8: Best Setting of Combination Parameters

Factor	Cycle Time	Warping
Mould Material	Qc 10	Qc 10
Mould Temperature	70	60
Melting Temperature	240	240
Ejection Temperature	110	90
Injection Pressure	120	120
Packing Pressure	110	90
Injection Time	1	1
Packing Time	6.5	6.5

From the calculation of cobribution's percentage from ANOVA in Table 9, the result shown that the ejection temperature, mould material and injection pressure has the most significant factor for determining cycle time because its P value is less than 0.05. Whereby the ejection temperature contributes the most which is 49.87%, followed by mould material 29.22% and injection pressure 11.38%. While for warpage defect, the result from Table 10 shows that melt temperature, ejection temperature, injection pressure and packing time were the most significant factor on warpage based on its P value is less than 0.05. The factor of melt temperature has the most percentage of cobributions which is 24.69%, followed by ejection temperature 20.71%, injection pressure 18.01% and packing time 12.72%.

The findings from the ANOVA tables were coincided with the practice in the industrial approach whereby sufficient melt temperatures will excited the molten plastic has a high fluidity during the filling stage, so that the mould can be filled easily. High injection pressure at optimized level will ensure sufficient molten plastic flows into the mould cavities so it will be fully filled and the part can be firmly compressed. The ejection temperature will ensure at optimized condition where the moulding part are firm and rigid enough to sustain the ejection force to avoid warpage during ejection process. The packing time must also be at optimized level as the degree of warpage are at minimal level and meet the product quality assurance. In the mean while by using high thermal conductivity material will remove heat more effectively because of the heat flux increases linearly with thermal conductivity. Based on the simulations, by using the optimal parameter levels and high thermal conductivity for mould tools will influence cycle time of the moulding process and finally minimize the warpage of the part

Table 9: Calculation of ANOVA for cycle time

Source	**DF**	**Sum of Squares**	***P(%)***	**F**	**P**	**Statistical significance**
Mould Material	2	97.608	29.22	8.08	0.008	Highly
Mould Tempt.	2	6.657	1.99	0.80	0.478	significance
Melt Tempt.	2	9.168	2.74	1.10	0.371	Not significance
EjectionTempt.	2	166.564	49.87	19.92	0.000	Not significance
Injection Pressure	2	38.025	11.38	3.35	0.047	Highly
Packing pressure	2	6.888	2.06	0.82	0.466	significance
Injection Time	2	4.600	1.38	0.55	0.593	Significance
Packing Time	2	2.675	0.80	0.32	0.733	Not significance
Error	10	1.811	0.54			Not significance
Total	26	333.994	100			Not significance

Table 10: Calculation of ANOVA for warping

Source	**DF**	**Sum of Squares**	***P(%)***	**F**	**P**	**Statistical significance**
Mould Material	2	0.0122	3.40	1.35	0.302	Not significance
Mould Tempt.	2	0.0105	2.92	1.17	0.350	Not significance
Melt Tempt.	2	0.0887	24.69	9.82	0.004	Highly
Ejection Tempt.	2	0.0744	20.71	8.25	0.008	significance
Injection	2	0.0647	18.01	7.17	0.012	Highly
Pressure	2	0.0180	5.01	2.00	0.186	significance
Packing pressure	2	0.0149	4.15	1.64	0.242	Significance
Injection Time	2	0.0457	12.72	3.40	0.045	Not significance
Packing Time	10	0.0301	8.38			Not significance
Error	26	0.3592	100			Significance
Total						

Conclusion

In this analysis, three different types of mould material were used, are Tool Steel (P-20), Aluminum Alloy (QC-10), and Copper Alloy (Be-Cu C18000) in order to perceive the most significant factor that contributes to reduce cycle time and warpage. Seven parameters of injection process have been sensibly designated to be used in the study such as melt temperature, ejection temperature, mould temperature, injection pressure, packing pressure, injection time and packing time. Moldex 3D has been used to simulate the injection molding process and the result has been analyzed by the Taguchi orthogonal array method and Analysis of Variance (ANOVA). The conclusions of the study are as follows.

- The established rankings for improving cycle time are cycle ejection temperature (rank 1), mould material (rank 2), Injection pressure (rank 3), Melting temperature (rank 4), mould temperature (rank 5), packing pressure (rank 6), Injection time (rank 7) and packing time (rank 8). From the calculation of ANOVA, Ejection temperature is the most significant which is 49.87% followed by mould material 29.22% and injection pressure 11.38%. The other selected parameters are less significant due to the P value is greater than 0.05.
- For improving warpage, the established rank are Melting temperature (rank 1), ejection temperature (rank 2), and Injection pressure (rank 3), packing time (rank 4), packing pressure (rank 5), Injection time (rank 6), mould material (rank 7), and Mould temperature (rank 8). The most effective factor from the ANOVA calculations that contributes to reduce warpage are melt temperature, which has the most percentage of cobributions with the value of 24.69%, followed by ejection temperature 20.71%, injection pressure 18.01% and packing time 12.72%. The other selected parameters are less significant due to the P value is greater than 0.05.
- From the parameters studied, several demonstrated to be significant contributors. Ejection temperature and injection pressure evidenced to be most significant contributors in both cycle time and warpage. The mould material selection proved to be most significance contributors in terms of cycle time, although a lesser degree of significant in warpage but still QC-10 showed the favorable results. Melting temperature demonstrated the highly significant contributors in terms of warpage, but a lesser degree of significance in cycle time. Packing time is one the significant contributor on affecting the warpage of the part. This finding also been proven by [4], [8] in their research project.

All factors that have the most and less significant impact on cycle time and the warpage has been exposed by the aid of simulation technology. This methodology reduces time by simulating it in software as compared to traditional trial and error experiment which also will increase costs.

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