Optimization of Plastic Injection tooling for Complex Feature Component

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Abstract- *This paper presents a study to determine the accuracy of wax patterns produced by soft tooling acrylonitrile butadiene styrene (ABS) to optimise the wax injection process parameters. Wax injection process parameter plays a vital role in the rate of production and the quality of the parts produced. The purpose of this paper is to estimate the optimum process parameter after pouring of wax material through wax injector in ABS dies. Furthermore, simulation study is performed using mold flow simulation software for optimum condition. Taguchi L9 orthogonal array is used as an experimental design and Analysis of variance (ANOVA) is further used to find which of the process parameters are statistically significant. the optimum setting result was found at mold temperature of 250° C, Melt temperature as 620°C and packing pressure as 1400°C respectively for filling time and for cycle time mold temperature 25°C, melt temperature 62°C and pressure 140 bar is the significant parameter.*

Keywords- (ABS) thermoplastic mold, Mold temperature, Melt temperature, cooling time, injecting pressure, Cycle time, Taguchi technique, ANOVA method

I. INTRODUCTION

Injection molding is one of the most popular techniques used in producing plastic parts and this process is most practical and cost effective for mass and batch production of polymer components [1]. It is a very intricate process due to various parameters that must be considered in product design and development base on “Form-Fit-Function” concept [2]. Cycle time is the manufacturing activity would like to have optimized productivity and quality. In injection molding of plastics, if quality is taken care of by part design, mold design and mold precision then productivity is also ensured on account of zero defect molding without rejection and to optimized cycle time. Cycle-time optimization starts at the design stage. The process are included like fill, pack, wrap, cooling and mold opening during cyclic operation of injection molding. By utilizing high pressure, the melted polymer can flow and can be forced into a cold mold; it will take the shape of the cavity. When the filling is nearly completed, the cavity is kept at a constant packing pressure to reduce shrinkage due to cooling. The cooling starts as soon as the plastic touches the mold walls. Then, the ejection is the final stage for extracting the plastic part from the cavity [2, 3]. Optimization of molding parameter is to make improvement in the part quality and reduce the defects that affect the cycle time in injection molding. The significant parameter that affects the cycle time in injection molding process is melting temperature, mold temperature, packing time, packing pressure, cooling temperature and gate location [4-7]. In order to produce the optimized setting for producing plastic parts, there are various tools and technique available to optimize. In this paper, we emphasize on Design of Experiment (DOE) which is the most efficient, quality improvement techniques to reduce process variation, emphasize process effectiveness and proficiency [8]. In the meantime, signal-to-noise (S/N) ratio is utilized to determine the optimum setting combinations of the process conditions for cycle time through analysis of variance (ANOVA). Extensive work has already been reported based on Taguchi and ANOVA technique for various responses for other plastic part components here study purposes only for the estimating optimum cycle time for optimized injection molding process parameters of the relay part component. The result from the simulation analysis have been optimized using Taguchi method and ANOVA technique in order to get the best parameter settings and to identify the most significant factors that affected the shrinkage, warpage and cycle time of the molded parts. The proposed flow chart shown in figure 1, gives the stepwise methodology which starts from 3D modeling until confirmation run.

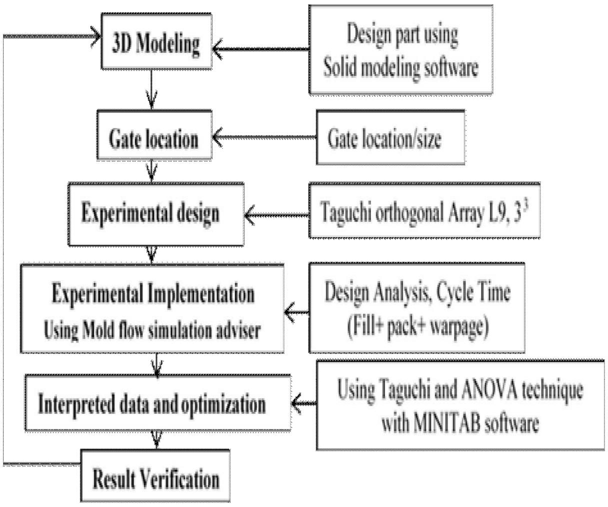


Figure 1. The Simulation flowchart

II. EXPERIMENTAL PROCEDURE

Design of part component - The CAD model of the component (Relay) was designed with the help of Creo-3.0 software and exported to the Autodesk simulation Moldflow adviser (ASMA) software in SAT (Standard ASCI Text) format [9].The dimensions of the part are (74.91×48.74×36.72) mm3. The appropriate location for the injection gate is (12.5, 5.03, and 14.74) mm in the X-Y-Z direction respectively. [10]

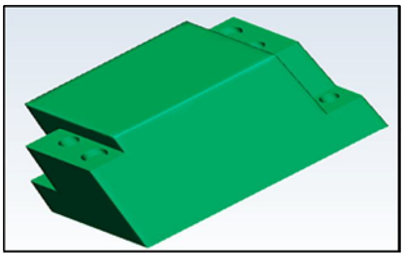


Figure2. Relay

1. **Gating location-** On ASMA software first of all "gate location analysis" is performed and results show that the best location is at the base of the part where the molten wax material flows in a sprue and gets solidified after some time. The gating suitability result is produced by the gate location analysis. Location of the injection gating for the part component is (-0.954, 48.743,-1.179) mm in X, Y and Z direction respectively.

2. **Material –** Cerita Wax F30-75 material is used for injecting molten material at one location. The molten wax material gets injected into digital ABS mold and solidifies after some time. It gets shrunk during phase change from liquid to solid and takes some time for solidification. The material is crystalline in structure and mechanical properties of this material are shown below in table [1].

Table 1. Mechanical properties of Cerita Wax F30-75 material

Elastic Property	E=2450 Mpa
Poison's ratio	$\mu = 0.38$
Shear modulus	G = 887.7Mpa
Coefficient of thermal expansion	$\alpha = 0.000249$
Melt density	$\rho = 0.955$ g/cm^3
Solid density	$\rho = 1.0215$ g/cm3

It is the most suitable material for injection into the mold die due to low cost, easily available and low density. The component produced from this material retains good processing stability, good strength and surface finish. It is the ideal material for creating injection molded parts that have reasonable molding temperatures (< 300 °C) and good flow behavior [9].

III. Optimum process parameter using Orthogonal arrays (OA) of Taguchi L9 Design of experiment -

In this study, Moldflow analyses were run according to L9 (33) orthogonal arrays. A total of nine simulation runs based on Taguchi orthogonal array design were performed by varying the following process parameters, namely the mold temperature, melt temperature and Packing pressure. The response for the same was considered as optimum cycle time (Fill+Pack+warp) during the injection molding process. The Taguchi technique employes the Signal to Noise (S/N) ratio to measure quality characteristics deviating from the preferred value. The characteristics of S/N ratio can be categories into three types: The nominal-the-best, the smaller- the-better and the larger the better. A selection of which OA to use mostly depends on these items in order of numbers of factors and number of levels. The response that was considered in Taguchi method is fill time and cycle time for these factors and levels [10-11].

Table 2. Process parameters and their levels

Process parameters	Experimental Levels		
	1	2	3
Mold temperature (°C)	25	27	29
Melt temperature (°C)	62	64	66
Packing Pressure (Mpa)	140	150	160

IV. RESULTS AND DISCUSSIONS

The responses for fill time and cycle time are presented in Table (3) below. Results were analyzed using "smaller the better approach" as this simulation is based on considering the minimum cycle time in injection molding process within optimal process parameter [12]. As a result the smaller-the-better quality characteristic is selected using equation (i)

S/N = -10log ½ $\sum_{i=1}^{n} yi^2$ --------- (i)

Table 3. Taguchi L9 (3 3) Orthogonal arrays for Fill time, Cycle time and S/N ratio

	Mold Temp (°C)	Melt Temp (°C)	Pressure (Bar)	Fill time(s)	S/N ratio	Cycle time (s)	S/N ratio
1.	1	1	1	6.231	-15.8912	95.11	-39.5645
2.	1	2	2	6.860	-16.7265	96.87	-39.7238
3.	1	3	3	7.289	-17.2534	98.71	-39.8872
4.	2	1	2	6.646	-16.4512	112.69	-41.0377
5.	2	2	3	7.174	-17.1152	114.48	-41.1746
6.	2	3	1	7.605	-17.6220	116.09	-41.2956
7.	3	1	3	6.956	-16.8472	153.30	-43.7108
8.	3	2	1	7.581	-17.5945	154.30	-43.7673
9.	3	3	2	8.008	-18.0705	155.89	-43.8564

Taguchi Analysis: Fill Time versus Mold, Melt, Pressure

Response Table for Signal to Noise Ratios

Smaller is better

Table 4. The response table of S/N ratios for Fill time

Level	Mold Temp (°C)	Melt Temp (°C)	Pressure (Bar)
1	-16.62	-16.40	-17.04
2	-17.06	-17.15	-17.08
3	-17.50	-17.65	-17.07
Delta	0.88	1.25	0.05
Rank	2	1	3

1. Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) is used to determine the percentage contribution of affecting parameters on the fill time and cycle time. This technique will compute the quantities such as the sum of squares (S), degree of freedom (f), F-static (F), Mean Square (MS) and percentage (P). For filling time, melt temperature is the parameter having the highest significant effect where as for the cycle time; mold temperature is the significant parameter having the greatest influence as shown in table (5) and table (7) respectively.

Table 5. Analysis of Variance for Fill Time, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Rank
Mold	2	0.78152	0.78152	0.39076	357.07	0.003	2
Melt	2	1.58341	1.58341	0.79170	723.46	0.001	1
Press	2	0.00205	0.00205	0.00102	0.94	0.517	3
Error	2	0.000219	0.00219	0.00109			
Total	8	2.36916					
S=0. 0330807	R-Sq= 98.91%	R-Sq (adj) =96. 63%					

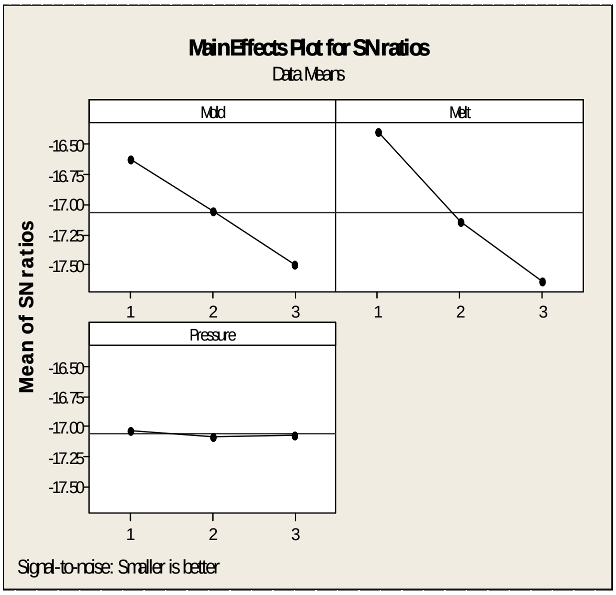


Figure 3. Effect of processing parameters on the Fill time

Table 6. The response table of S/N ratios for cycle time

Level	Mold Temp (°C)	Melt Temp (°C)	Pressure (bar)
1	-39.73	-41.44	-41.52
2	-41.17	-41.56	-41.54
3	-43.78	-41.68	-41.59
Delta	4.05	0.24	0.05
Rank	1	2	3

Table 7. Analysis of Variance for Cycle time, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Rank
Mold	2	5230.97	5230.97	2615.48	48514.73	0.000	1
Melt	2	15.34	15.34	7.67	142.28	0.007	2
Pressure	2	0.23	0.23	0.11	2.13	0.320	3
Error	2	0.11	0.11	0.05			
Total	8	5246.64					
S=0.232188	R-Sq = 97.00 %	R-Sq (adj) = 96.99 %					

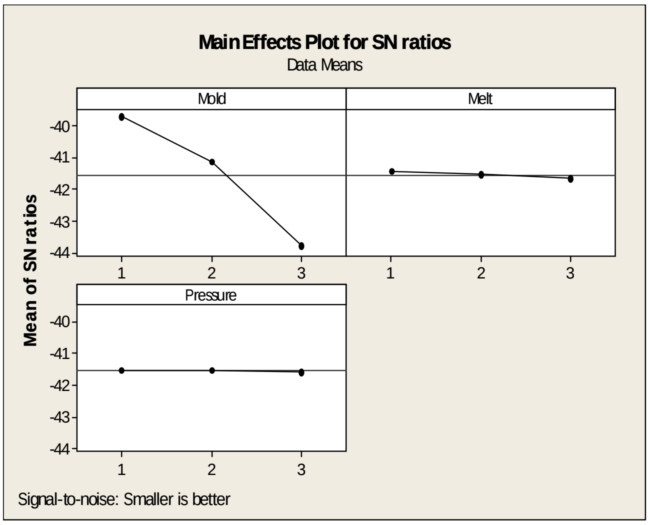
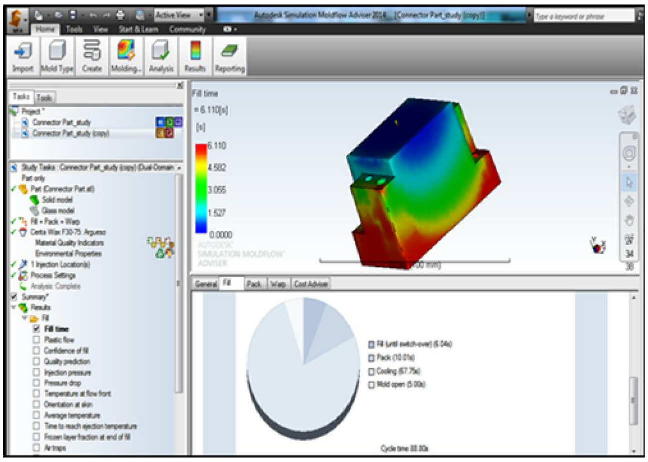


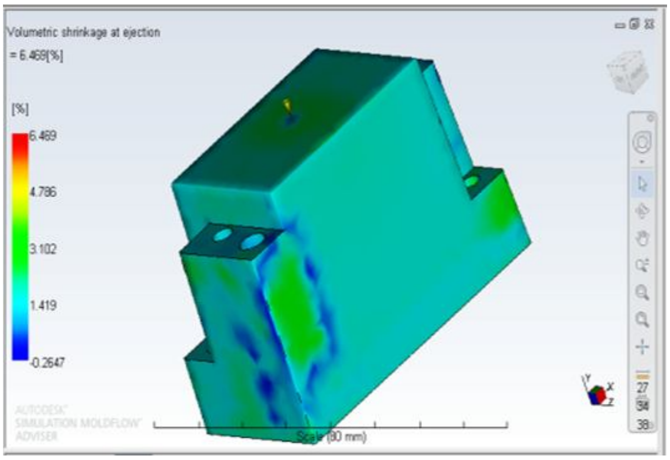
Figure 4. The effect of processing parameters on Cycle time

Figure (3) and (4) shows the S/N ratio response diagram for fill time and cycle time. Based on these figures, it can be easy to identify the optimal parameters of fill time and cycle time. Selecting the highest value among each point could identify optimization levels. The optimum setting of our result is presented in table (4) and table (6). It can be clearly concluded that from table (4) melt temperature was the most significant parameter on the effect of fill time and mold temperature is the most significant parameter for cycle time for completion of part component. Based upon the tables (4) and (6), the optimum setting result was found at mold temperature of 250 C, Melt temperature as 620C and packing pressure as 1400C respectively for filling time and for cycle time mold temperature 25°C, melt temperature 62°C and pressure 140 bar is the significant parameter.

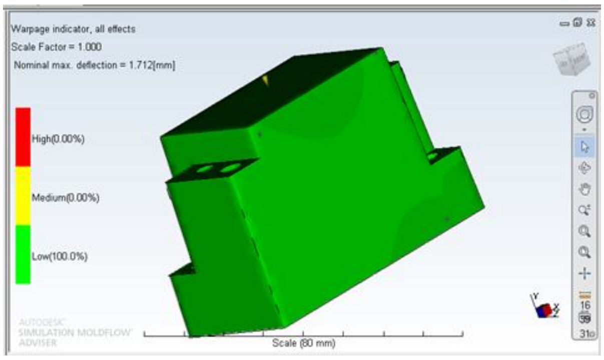
Validation using simulation study- Moldflow simulation analysis is accomplished to estimate the suitable material conditions required for part production at optimum levels for mold temperature (27°C), melt temperature (62°C) and packing pressure (140 bar). Figure (5) shows responses at optimum parameter for cycle time (88.80 sec), volumetric shrinkage (6.459 %), maximum deflection (1.712 mm) and cooling quality is (48.2 %). The purpose of molding windows is to improve manufacturability of the part and find the optimum cycle time. The injection time is shown on the x-axis whereas the y-axis shows melt temperature. The molding, windows is allocated into three portions which are green (preferred), yellow (feasible) and red is (unfeasible).



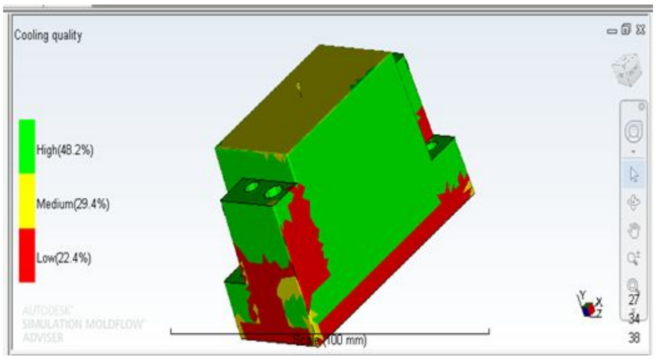
(a). Optimum cycle time = 88.80 sec



(b). Volumetric shrinkage= 6.459 %



(c).Maximum deflection= 1.712 mm



(d). Cooling quality = Green (Acceptable) = 48.2%

Figure 5. Responses at optimum process parameters (a) Optimum cycle time (b) Volumetric shrinkage (c) Maximum deflection (d) Cooling quality

The part produced by wax injector molding machine at these optimum parameters is widely acceptable as shown in Figure (6).

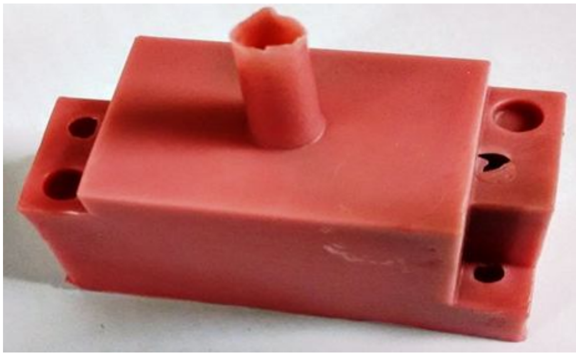


Figure7. Relay produced by wax injector at optimum parameter

V. CONCLUSION

Taguchi and ANOVA methods were utilized to find the optimum process parameter for fill time and cycle time using Autodesk simulation Moldflow software for the wax material when poured into a digital ABS mold die. Results shown that 62°C of melt temperature, 25°C of mold temperature and 220 MPa gave the optimum fill time and cycle time of the wax material. Based on this study, manufacturers ensure the better part production at optimum parameter with less defect error for part component.

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