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Time-Based Optimization of Injection Moulding Process Using Response Surface Methodology

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ABSTRACT

This Present study has been made to optimize the process parameters during forming of PVC (L-bow) fitting by injection moulding machine using response surface methodology (RSM).Four input process parameters of injection moulding machine namely filling time, refill time (RFT), tonnage time (TT) and Ejector retraction time (ERT)) is chosen as variables to determine the process performance in terms of cycle time (CT). The analysis of variance (ANOVA) is carried out to determine the effect of process parameter on process performance. The parameters filling time (23), refill time (36) tonnage time (0.68) and Ejector retraction time (1.36) are identified as the most significant optimal setting for Cycle time (CT).

Key words: Injection moulding, Response surface methodology (RSM), ANOVA

INTRODUCTION

Injection moulding is a challenging process for many manufacturers and researchers to produce the products fulfilling the requirements and maintaining the desired quality at lowest cost. More complexity and parameter manipulation may affect the quality of product and high manufacturing cost. The main aim in injection moulding is to make improvement in the quality of the product, reduction in cycle time and lower manufacturing cost. Injection Moulding (IM) technology allows to produce complex shaped parts in short cycle time, in large quantities with good dimensional accuracy. The problems related to quality and rate of production has a direct impact on the expected profit for injection moulding industries. Quality characteristics in injection moulding are classified as mechanical properties, dimensions or measurable characteristics and attributes. Any manufacturing activity would like to have optimized productivity and quality. In injection moulding of plastics, if quality is taken by considering part design, mould design and mould precision, then productivity is also ensured on account of zero defect mounding without rejection and cycle time is optimised. Response surface methodology (RSM) is a collection of statistical and mathematical methods that are useful for modelling and analyzing engineering problems. The cycle time can be considered as the most important factor from the point of view of manufacturing industries for better production rate. Based on customer demand, it is important to give better quality, minimum cost of product. It is a characteristic that improve the production cost of the product.

Manufacturing products have two most significant problems and these are process modelling and optimization. The manufacturing processes are characterized by multiplicity of dynamically interacting process variables. In recent years various significant advantages have been found in injection moulding. Literature review, simulation and optimization system were designed by using different cutting parameters and optimization methods. Some of literature studies are as follows:

Bano et al [1] applied RSM to optimize the injection moulding process Parameters. The process parameters selected in this study are the mould temperature, injection pressure and screw rotation speed. The optimal process parameter setting found to minimize the defect by Chiang et al [2]. The experiments were done on injection moulding machine and optimized through response surface methodology. The mold temperature (MT), packing time (Pt), packing pressure (PP) and cooling time (Ct) in the packing stage are considered as machining parameters. They found good agreement between the model results and experimental values. Kavade et al [3] operated and optimized the process for polypropylene in injection moulding in search of an optimal parameter combination, (favourable process environment) which is capable of producing desired quality of the product in a relatively lesser time.

Chen et al [4] conducted the effect of process parameters mould temperature, holding pressure, melting temp, position in injection moulding machine of using Taguchi Method. Where melting temperature, holding pressure, and injection location are found to be statistically significant. Xia et al [5] shows the correlation of process parameters in injection moulding machine. And this provides strong theory and feasible algorithm for adaptive intelligent optimization and controlling of the parameters in injection process. McCread et al [6] conducted the experiment on injection moulding machine. ANN/GA method is used in the process optimization for an industrial part in order to improve the quality index of the tric shrinkage variation in the part. Hussin et al [7] experimented the injection moulding and optimized the process with computer simulation which provides an efficient and economical way of replacing the traditional method of trial and error. In [8] Mehat et al presented the optimization method of injection moulding process, parameters are proposed systematically in reducing the shrinkage problem in plastic moulded gear as an application. Optimization method appears to be a necessity to overcome the shortcomings in multiple quality characteristics optimization as well as provides a statistical solution in defining a weight for each quality characteristic. Stanek et al [9] conducted the injection moulding process optimisation .The results revealed the reduction in the injecting cycle. The aim of optimization is not only to correct process condition setting and eliminating all defects made during production but also minimizing the total time of the injecting cycle which has a great economical impact. Pareek et al [10] presents an experimental study related to the Optimization of injection moulding. Process parameters will be carried out using polypropylene (PP) as the moulding material. The study says that temperature is found to be the most significant factor followed by cooling time and injection pressure.

The Cycle time have been identified as quality aspects and are assumed to be directly related to performance of mechanical sections and production rate. Beside from quality, there exist another criterion called Productivity which is directly proportional to the profitability and goodwill of an organization. For these reasons, there has been research and development with an aim of optimizing the moulding process to obtain desired results. RSM is a collection of mathematical and statistical procedures and good for the modelling and analysis of problems in which the desired response is affected by several variables. The mathematical model of the desired response for several independent input variables is gained by using the experimental design and applying regression analysis. The key objective of present work is to identify the efficient optimal parameter for multiple quality characteristics by using the CT (Cycle time) as multi objective functions via Response surface methodology in injection moulding process.

ASSUMPTIONS

The analytical study remains valid under the following assumption -

- The processing times which are not varying frequently in the injection moulding process must be considered in Cycle time (CT).
- Any error in the guide ways along which the nozzle moves has no effect on the size and shape of the product.
- Time can be neglected which is affected in cycle time due to vibration.

EXPERIMENTAL DETAILS

In this experimental study, the material to be machined is PVC with various chemical compositions. Examination of process row material polyvinylchloride $(C_2H_3Cl)_n$ was carried out using as per the requirement. The process operations are taken as per the conditions given by the design matrix randomly so as to avoid the mathematical errors. The Cycle time can be taken as output in this study.

Fig. 1 Injection moulding machine and Product

EXPERIMENTAL DESIGN

Response Surface Methodology

Response surface methodology emphasises on a well- known most widely used approach on the optimization of the input parameters model. In statistics, response surface methodology (RSM) explores the relationships between several explanatory variables and one or more response variables. The main idea of RSM is to use a set of designed experiments to obtain an optimal response. Central composite design can be implemented to estimate a polynomial model. These models known as independent variable based on either simulation experiments, experimental observations, physical experiments.In this work, response surface modeling (RSM) is utilized for determining the relations between the various time parameters with the various machining criteria and exploring the effect of these time parameters on the responses, i.e. the cycle time. In order to study the effects of the time parameters on the above mentioned machining criteria, second order polynomial response surface mathematical models can be developed [11].

In our study the relationship between the input parameters, filling time (FT), refill time (RFT), tonnage time (TT), Ejector retraction time (ERT)) and the output Z defined as machinability features, Cycle time (CT)

$$Z = \varepsilon\ (FT, RFT, TT, ERT) \tag{1}$$

Where ε is the response function. At most, response surface methodology has a functional relationship between input variables and output variables and this relation can be expressed by second order polynomial equation which is given below

$$\varepsilon = b_0 + \sum_{i=1}^{n} b_i X_i + \sum_{ij}^{k} b_{ij} X_i X_j + \sum_{i=1}^{n} b_{ii} X_i^2 \tag{2}$$

Where ε is the estimate response (Cycle time), The terms b_0, bi are the second order regression coefficients and b_{ii}, b_{ij} represent the pure second order quadratic effect X_i, X_j represent the inter active terms which deal the interactive effects of the process parameters, k represents the number of machining parameters i.e., variables considered for the research investigation, Z represents the corresponding response of the process characteristics. X represents the coded variables.

The common method used in RSM is regression method based on least square method. This method is usually used to identify the regression coefficient which is shown in the following equation [13].

$$b = \begin{bmatrix} b_0 \\ b_1 \\ \cdots \\ \cdots \\ b_r \end{bmatrix} = (X^T X)^{-1} X^T \eta = \left[\frac{1}{P} \sum_{j=1}^{k} \eta_j\, , \frac{\sum_{j=1}^{P} X_{1j}\eta_j}{\sum_{j=1}^{P} X_{1j}^2}, \ldots\ldots, \frac{\sum_{j=1}^{P} X_r \eta_j}{\sum_{j=1}^{P} X_{rj}^2} \right]^T \tag{3}$$

Where, p known as number of factor and r represent the number of objective function. The b term consist a set of unknown parameter that can be estimated by collecting experimental system data. These data can be collected either by physical experiments or by numerical experiments. The parameters can be selected by regression analysis based on experimental data.

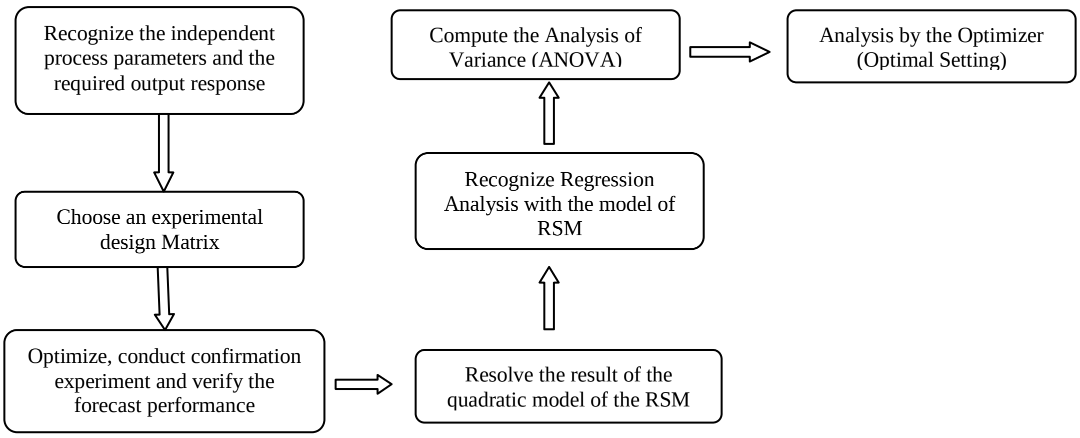


Fig. 2 Step of Response surface methodology

EXPERIMENTAL PROCEDURE OF INJECTION MOULDING MACHINE

According to the literature survey and on the basis of specification of material, finally the four Process parameters and their level of experiments are selected in this work. These parameters are filling time (FT), Refill time (RFT), Tonnage time (TT) and Eject retraction time (ERT). The experimental conditions are in the Table 2. The Mathematical models based on second order polynomial equations were established for Cycle time using the experimental outcomes which is shown in Table 2**.**Table 3 represents the coefficients of regression analysis for Cycle time along with their p- values of the parameters, higher order and interactions**.** The p-value of regression analysis of Cycle time in Table 4 indicates that linear effect of filling time(FT), tonnage time (TT), Ejector retraction time (ERT) have significant effect while Refill time (RFT) shows insignificant effect on Cycle time (CT). In case of Square and interaction term, all the parameters have insignificant effect. The impact of each process parameter can be more clearly shown in fig. 3, with response graphs.

Table -1 Process Time and their Levels

Symbol	Factors	Units	Level 1	Level 2	Level 3
FT	Filling time	Sec.	23	24	25
RFT	Refill time	Sec.	36	37	38
TT	Tonnage time	Sec.	.68	.70	.72
ERT	Ejector retraction time	Sec.	1.36	1.38	1.40

Table -2 Experimental Design Matrix with their Results

Exp. No.	Control factors level				Cycle time (CT)
	Filling time (FT)	Refill time (RFT)	Tonnage time (TT)	Ejector retraction time (ERT)	
1.	23	36	0.68	1.36	95.03
2.	25	36	0.68	1.36	96.88
3.	23	38	0.68	1.36	95.89
4.	25	38	0.68	1.36	96.96
5.	23	36	0.72	1.36	95.68
6.	25	36	0.72	1.36	97.27
7.	23	38	0.72	1.36	95.25
8.	25	38	0.72	1.36	97.50
9.	23	36	0.68	1.40	95.61
10.	25	36	0.68	1.40	97.30
11.	23	37	0.68	1.40	95.37
12.	25	38	0.68	1.40	97.45
13.	23	36	0.72	1.40	95.76
14.	25	36	0.72	1.40	97.70
15.	23	38	0.72	1.40	95.89
16.	25	38	0.72	1.40	97.50
17.	23	37	0.70	1.38	95.90
18.	23	37	0.72	1.38	95.85
19.	24	38	0.72	1.38	96.20
20.	24	38	0.70	1.38	96.10
21.	24	37	0.68	1.38	96.13
22.	24	36	0.72	1.38	96.18
23.	24	36	0.70	1.36	96.00
24.	24	37	0.68	1.40	96.33
25.	24	37	0.68	1.36	96.20
26.	24	37	0.72	1.36	96.30
27	24	37	0.70	1.40	96.50
28	24	38	0.72	1.40	96.78
29	24	37	0.70	1.38	96.68
30	24	37	0.72	1.38	96.45
31.	24	36	0.70	1.38	96.40

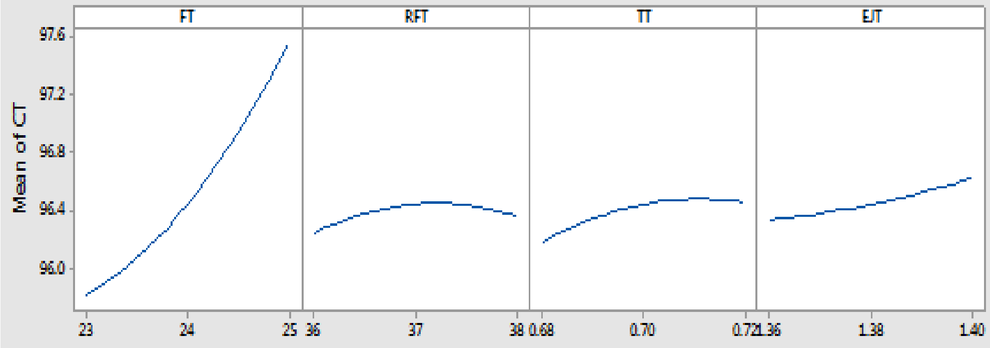


Fig. 3 Effect of parameters on Cycle Time (CT) (fitted means)

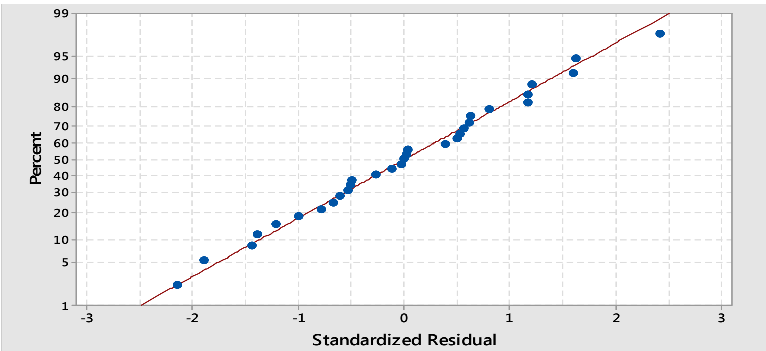
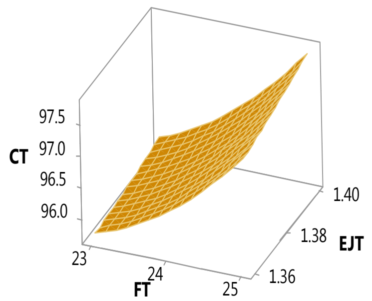


Fig. 4 Normal probability plot of residuals for CT (Cycle time)

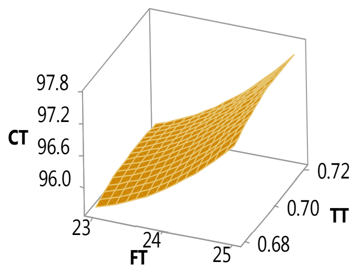
This fig. 3 helps to find out the ideal Process parameters (the level with the highest point on the graphs) as well as to achieve the effect of each parameter. The line in Fig. 3, which connects between the levels, can clearly show the powerful impact of each control factor. Especially, the Filling time (FT) shows a strong effect on Cycle time (CT). The Refill time (RFT) has insignificant effect which is clearly shown in Fig.3.

Table -3 ANOVA of Quadratic Response Surface Design for Cycle Time

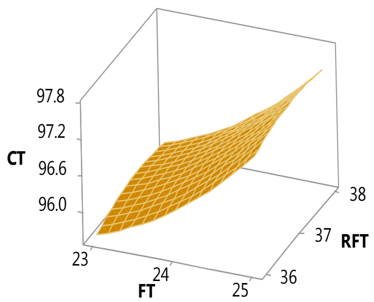
Source	DF	Adj SS	Variance	F-Value	P-Value
FT	1	11.6805	11.6805	217.44	0.000
RFT	1	0.0606	0.060	1.13	0.304
TT	1	0.0730	0.3831	7.13	0.017
ERT	1	0.4410	0.4410	8.21	0.011
FT*FT	1	0.2602	0.2602	4.84	0.043
RFT*RFT	1	0.0872	0.0872	1.62	0.221
TT*TT	1	0.0554	0.0554	0.08	0.325
ERT*ERT	1	0.0045	0.0045	1.03	0.777
FT*RFT	1	0.0074	0.0239	0.14	0.716
FT*TT	1	0.0239	0.0199	0.45	0.514
FT*ERT	1	0.0199	0.0730	0.37	0.551
RFT*TT	1	0.0098	0.0098	1.36	0.261
RFT*ERT	1	0.8595	0.0240	0.45	0.513
TT*ERT	1	0.0240	0.0537	0.18	0.674
Error	16	0.3831	0.0074		
Total	30				



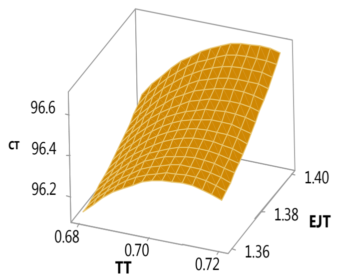
Surface plot of CT vs EJT, FT



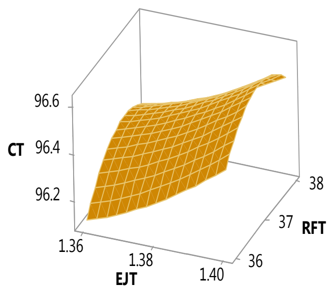
Surface plot of CT vs TT, FT



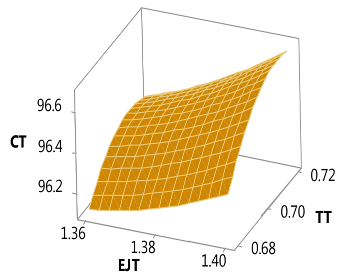
Surface plot of CT vs RFT, FT



Surface plot of CT vs EJT, TT



Surface plot of CT vs RFT, EJT



Surface plot of CT vs TT, EJT

Fig. 5 Response surface plot showing the effect of two variable on P (the other variable is held at constant level)
FT (Filling Time),RFT (Refilling Time), TT (Tonnege Time), ERT (Ejector retraction time)

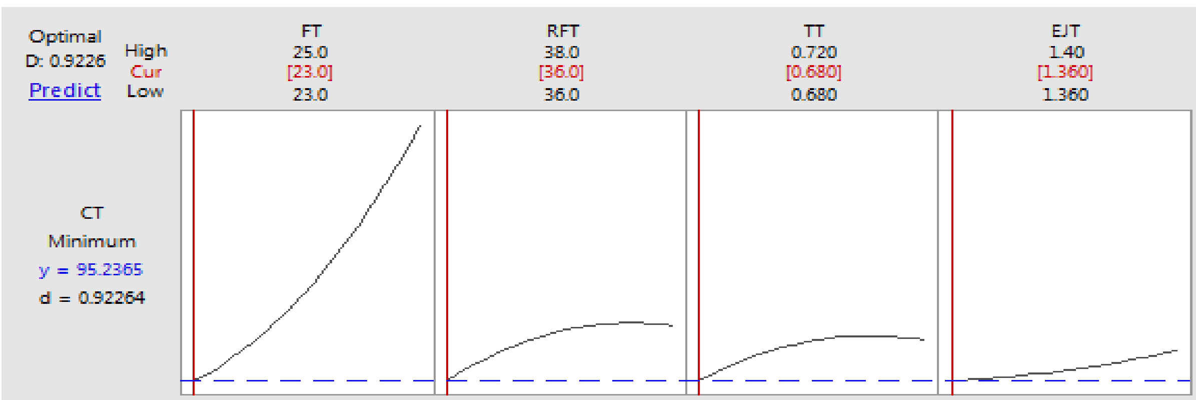


Fig. 6 Optimum result of minimum cycle time

CONCLUSION

In this work, the application of response surface methodology (RSM) on PVC (C2H3Cl)n material on injection moulding machine are explained. In addition, a quadratic model is established for Cycle Time (CT) so as to examine the influence of process parameters on it. Following are the results to be found:

- From the ANOVA it is proved that with the help of quadratic mathematical model the prediction of Cycle Time (CT) with 94.21%. Confident interval.
- All the cutting parameters have significant effect but filling time(FT), tonnage time (TT), and Ejector retraction time (ERT) have the most significant effect with the contribution of 85.26%, 1.92% and 3.10% respectively in the total variability of model.
- ANOVA shows that square and interaction terms between the parameters have insignificant effect on Cycle time.
- To find the optimal processing condition for minimum Cycle time (CT) for applicability of desirability function approach.

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