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OPTIMIZATION OF INJECTION MOLDING PROCESSING PARAMETERS BASED ON THE MINIMIZATION OF VOLUMETRIC SHRINKAGE: RSM APPROACH

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Abstract

This work has been focused on the optimization of the process parameters affecting the volumetric shrinkage using the DOE response surface methodology. The main objective of the work is to minimize the volumetric shrinkage using response surface method. To achieve the optimum parameters, a face centered CCD was used to statically visualized the complex interaction of melt temperature, mold temperature, packing time, packing pressure and cooling time on the volumetric shrinkage. In this optimization the response surface methodology is highlighted with 0.9956 composite desirability value. Response surface methodology is used to obtain the relationship between process parameters of injection molding process. A regression model is developed to predict the volumetric shrinkage. The ANOVA is kept to describe the coherence of regression model and explore the statistical significance of factors. In addition, the relationship between volumetric shrinkage and process parameters of injection molding is presented using 2D contour and 3D surface plot. Second order response surface models were obtained to be the most suitable in the present investigation. The developed models have been compared with previous work and which is found the improvement in the volumetric shrinkage with optimum process parameters.

Keywords: *Injection Molding, Process Parameter, Volumetric Shrinkage, RSM, Optimization.*

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1. Introduction

Determining the parameters of the molding process plays an important role in plastic injection molding. The quality of the molded part, including strength, deformation, and residual stress, is greatly affected by the conditions in which it is processed. It also affects the productivity, cycle time, and energy consumption of the molding process. Molding conditions are closely related to other factors such as materials, part design, and equipment, which determine the quality of plastic products [3]. Kurt et al. Experimentally investigated the plastic injection molding process, looking at the effect of process parameters on the quality of final parts. The results of this experimental study indicated that cavity pressure and mold temperature are the major factors determining the quality of the final product in plastic injection molding [4].

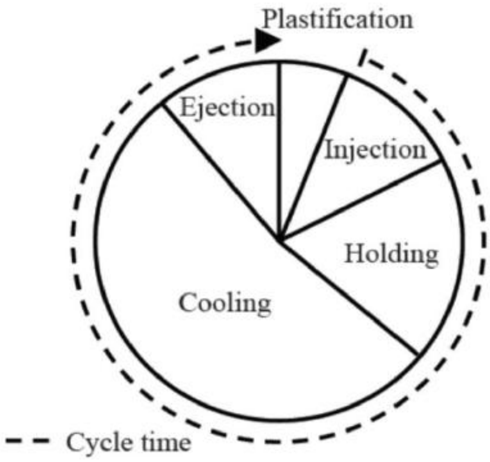

Figure 1. Injection moulding cycle and steps included in the cycle time

2. Methodology

Injection molding is one of the most widely used manufacturing processes for polymer materials due to its high production rate and low process cost. However, the polymer parts created by the injection molding process suffer from various defects, such as geometric defects, shape-related defects, and visual defects. In this section, the method of problem solving i.e. response surface methodology has been discussed.

The work is conducted by literature Ramakrishnan and Mao [17] on injection molding process with a polymer material i.e. Delrin acetal 500P grade. The properties if Delrin acetal 500P and conditions are shown in Table 1. This experimental data and work data have been selected for optimization from reputed literature Ramakrishnan and Mao [17].

Table 1. Process Delrin acetal 500P grade polymer material [17]

S. No.	Description	Unit	Value
1	Density	Kg/m^3	1420
2	Yield Stress	MPa	70
3	Tensile Modulus	MPa	3100
4	Flexural Stress	MPa	80
5	Flexural Modulus	MPa	2900
6	Strain at Break (50mm/min)	%	40

During the experiments the injection molding parameter for Delrin acetal 500P grade polymer material is given below in Table 2.

Table 2. Experiments and corresponding parameter of injection molding [17]

S. No.	Description	Unit	Value
1	Melt Temperature	ºC	1420
2	Mold Temperature	ºC	70
3	Hold Pressure	MPa	3100
4	Drying Temperature	ºC	80
5	Molding Shrinkage (i) Normal (ii) Parallel	%	(i) 1.9 (ii) 2.0

Table 3. Initial screening parameters and their levels for injection molding process [17]

Control Factors	Code Parameter	Level				
		-2	-1	0	1	2
Melt Temperature (ºC)	T_{melt}	205	210	215	220	225
Mold Temperature (ºC)	T_{mold}	80	85	90	95	100
Packing Time (sec)	T_p	10	20	30	40	50
Packing Pressure (MPa)	p_p	80	85	90	95	100
Cooling Time (sec)	T_C	50	60	70	80	90

3. Results and Discussion

Some researchers have tried several approaches to obtain the optimal setting of injection molding process parameters while producing a consistent quality of molded products. Determining the optimal setting of process parameters has a significant impact on production quality and cost. It is necessary for the industry to obtain the optimal parameters of the molding process in order to improve product quality, reduce production costs, and improve turnover limits.

The regression equation developed from the ANOVA for evaluating the volumetric shrinkage within the limits of the factors is found as follows:

Volumetric Shrinkage = 1.4 + 0.097 Tmelt - 0.081 Tmold + 0.0864 Tp + 0.063 pp - 0.0322 Tc - 0.000140 Tmelt*Tmelt + 0.000096 Tmold*Tmold + 0.000070 Tp*Tp - 0.000811 pp*pp- 0.000009 Tc*Tc + 0.000207 Tmelt*Tmold - 0.000432 Tmelt*Tp + 0.000307 Tmelt*pp ---(1)

The Figure 2 indicates the residual plot of the work as a normal probability of prediction or regression plot, versus fit value, histogram and order of observation of the model. It can be seen that the residuals typically fall on or near a straight line, showing that the errors are normally distributed.

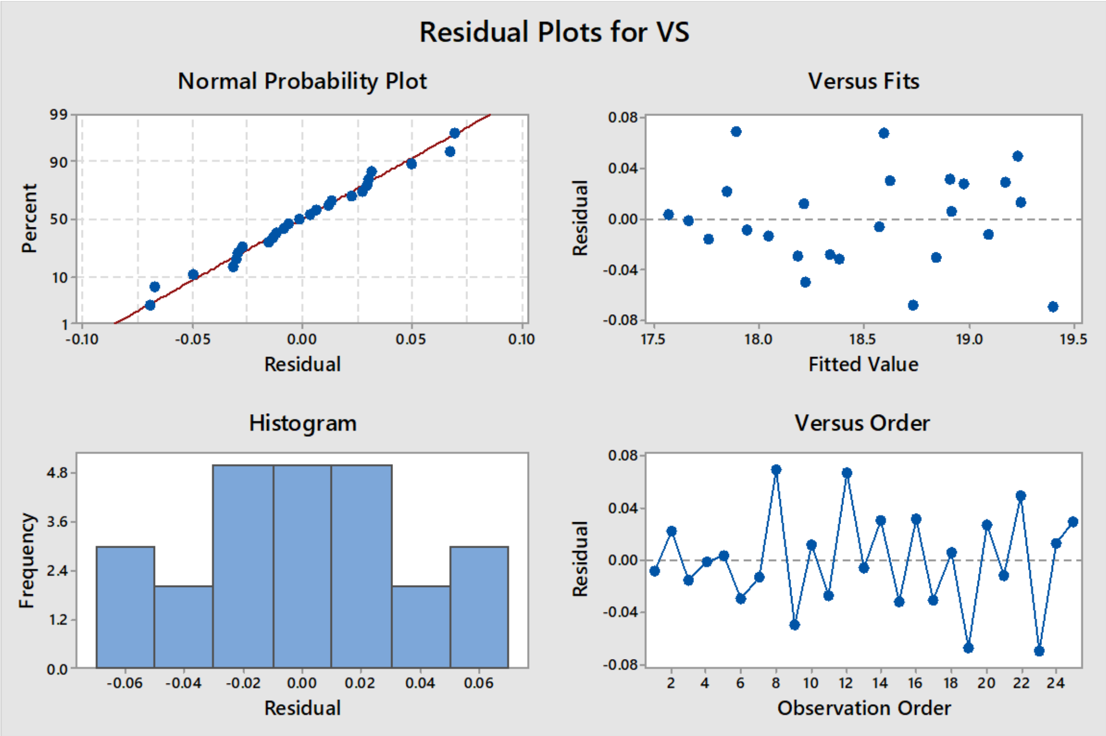

Figure 2. Residual plot for the volumetric shrinkage

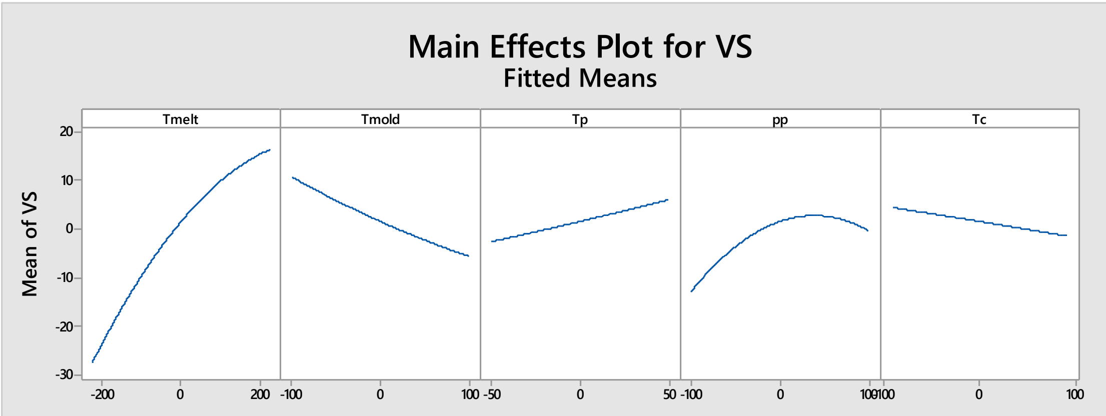

Figure 3. Main effect plot of interaction from model

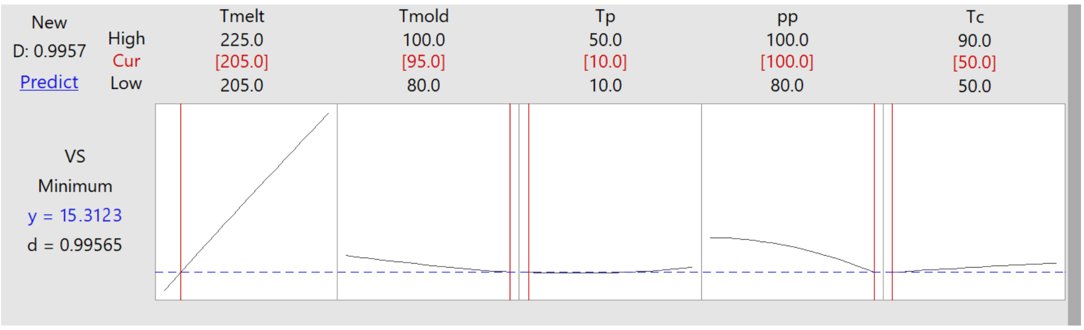

Figure 3. Optimization of process parameter with respect to response obtained from RSM Minitab 17.0

The input data taken from the literature Ramakrishnan and Mao [17] are predicted by using response surface methodology (RSM) in Minitab 17.0 and this optimum response has been compared to literature Ramakrishnan and Mao [17] as shown in Figure 3.

4. Conclusion and Scope of Further Work

- The response surface model fits well to the larger shrinkage analysis data with a correlation coefficient, R-squared (adjusted) and R-squared (predicted) values greater than 92%, respectively.
- The work was done and the predicted value results were compared. The maximum error between the current prediction value and the literature [17] is approx. 12.833%, which indicates that the regression model has high precision in predicting volumetric shrinkage.
- The Taguchi technique is commonly used only in linear interactions. This is due to the fact that in the Taguchi design, interactions between control factors are aliased with their main effects. 3D surfaces generated by RSM can help visualize the effect of parameters on the response over the entire specified range, while the Taguchi technique gives the average value of the response at a given level of parameters. Therefore, RSM is a promising analytical tool to estimate the response that fits the range of parameter studies.
- The further future work of the that present results will be extended and tested in a large-scale industrial setting, not only for volumetric shrinkage but also for other response like ware page, flow line, vacuum voids, surface delamination, strength of the product etc. In future work is also done in different material type with different techniques.

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