

# Optimization of Injection Molding Process Parameters by Response Surface Methods

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## Opinion

Injection molding is an important manufacturing process for the mass producing of plastic products in complex shapes and sizes with high precision. In recent years, the production of injection molded plastic products has increased rapidly because plastic products are light in weight, low in price and fast for shape forming, thereby making them more popular than the metallic ones. As a result of growing plastics applications, increasing customer demand and rapid growth of the global marketplace, the quality requirements of injection molded products have become more stringent.

Even though the product quality is the key concern of the customers but it is difficult to predict, control and inspect by the machine and production operators during the product development stage. Since, the product quality requirements become more stringent in the plastic industry, the determination of the optimal injection molding process parameters for development of new products and the improvement of existing product quality has become an active research area. The setting of process parameters and their optimization are recognized as important approaches to improve the quality of the molded products at no additional cost for mold repairs. However, the optimization of process parameters is a complex and difficult task, because it depends on many factors, such as the molding material, the mold and product design, and the molding machine [1].

Inappropriate settings for parameters may cause production and quality problems [2]. These molding parameters may affect the quality of the molded products. Small changes of molding parameters may give a significant impact to the plastic material's characteristics. Many experimental works were carried out to investigate the influence of the injection molding parameters on the quality of molded products and the occurrence of molding defects [3]. For example, increasing both the packing pressure and packing time could reduce the 'sink marks', while decreasing the injection speed could eliminate the 'flow marks'.

Traditionally, process parameters of injection molding are determined by experienced machine operators. Setting these parameters is a highly skilled job and based on the skilled machine operator's knowledge acquired through long experience rather than through any theoretical or analytical approach [1]. During mold trials, the machine operator will set up an initial process setting based on his experience. The machine operator will then have a mold trial at that setting and usually may encounter some defects in the trial products. Accordingly, the machine operator will adjust the process parameters to a new setting and repeat mold trial. The above adjustment will be repeated until the molding trial is fully successful, i.e. without producing any defect [4]. Another traditional approach is the "one-factor-at-a-time" approach (OFAT) where one process parameter is

varied at a time instead of all simultaneously until the quality of the molded products is found to be satisfactory [5]. The optimal injection process parameters obtained by both these approaches during trials will be recorded in a report form. The molded product produced by using the optimal injection process parameters will be inspected according to the inspection checklist by the QC before approval for mass production. The production operators usually only perform the inspection of the molded products by checking several quality characteristics of the product like weight, appearance and some critical dimensions.

The demand for experienced machine operators is increasing in the molding industry. Machine operators need many years to gain the necessary experience. In a competitive environment the trial-and-error approach by the experienced machine operators is very expensive and time consuming [1]. Furthermore, the quality of the product produced by this approach may still be inconsistent at times. The OFAT approach may also face some difficulty in obtaining the optimal process parameters setting due to the large number of parameters involved and the time constraint [6]. The OFAT approach also ignores the effect on injections by interaction between parameters, which in fact occur. Therefore, both approaches are no longer good enough and not economical enough for obtaining the optimal process parameters in the competitive environment of injection molding industry [7].

Only a few researchers have attempted various approaches to find the optimal injection molding process parameters setting producing consistent quality of molded products [8]. The determination of the optimal process parameter setting critically influences the quality and production cost. It is necessary for the industry to obtain the optimal molding process parameters more precisely to improve the product quality, reduce the production cost and improve the profit margin.

In this article the authors suggested to determine the optimal injection molding process parameters setting by response surface methods (RSM). The RSM was used to optimize the quality characteristics by determining the most appropriate and accurate molding process parameters setting [9]. Long et al. [10] study the molding process parameters in manufacturing of plastic bra-cups, whereby the optimal process parameters setting was determined by evaluating the main and interaction effects by RSM, to obtain a desirable response. Mathivanan et al. [11] developed a nonlinear mathematical model of injection molding parameters to determine the optimal process parameters using RSM. Chuang et al. [12] applied RSM to determine the optimal parameters of injection molding process for manufacturing thin-shell plastic parts. Lin et al. [13] applied RSM to discuss variation of mechanical characteristics in three different types of composites.

The Response Surface Methods (RSM) is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest influenced by several variables is to be optimized. It is useful to optimize the response variable when values of the factors are continuous [14]. For instance, to find the levels of  $k$  factors from a continuous range of values,  $x_1, x_2, \dots, x_k$ , that will maximize or minimize the response variable of a process or product. The response variable is a function of  $x_1, x_2, \dots, x_k$ , the variables representing the factors, with as the experimental error.

$$y=f(x_1, x_2, \dots, x_k)+\varepsilon$$

The surface represented by  $f(x_1, x_2, \dots, x_k)$  is called a response surface, graphically represented as a surface in a  $(k + 1)$  dimensional space. In most RSM problems, the true response function  $f(x_1, x_2, \dots, x_k)$  is unknown and the success of the experiment depends critically on how well  $f(x_1, x_2, \dots, x_k)$  can be approximated.

The Full Factorial Design (FFD) with Center Point (CP) experimental study was applied to determine the optimal process parameters setting which could be set to maintain the dimensions of the responses as close to the target values as possible. Subsequently, an approximate first-order model was developed if the curvature is insignificant. If the curvature is significant, the RSM via Central Composite Design (CCD) experimental study was applied to determine the optimal process parameters setting which could be set to maintain the dimensions of the responses as close to the target values as possible. Subsequently, an approximate second-order model was developed.

The RSM is a strategy to achieve this goal that involves experimentation, data analysis, modelling and optimization. The RSM is a sequential procedure. In order to develop a proper approximation for response variable, the experimenter usually starts with a first-order model. The main goal is to determine whether the current operating condition or levels of the factors are close to optimum of the response surface or far from it. When the experimental region is far from the optimal region of the surface, a first-order model approximation of the surface should be adequate.

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