International Journal of Modern Agriculture
ISSN: 2305-7246
Volume 10 Issue 1, 2021

Modern Approaches for Optimization of Process Parameters of Plastic Injection Moulding – A Review

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Abstract–

In plastic injection moulding, process parameters have an effect on production. The value of the process parameters depends on different ideas, such as plastic type, object size, dimensional tolerances, etc., so there are no set values and formulas for different process parameters. For many manufacturers, injection moulding has always been a process to produce Lui that meets the requirements at the lowest cost. In the face of global competition in the injection moulding industry, it is no longer sufficient to use the trial and error method to determine the injection moulding process parameters. The factors that affect the quality of moulded parts are divided into four categories: part design, mould machine performance, and processing conditions. Parts and moulds are assumed to have been established and fixed during the production process due to machine wear, environmental changes, changes in the environment, changes in the environment, changes in the environment, or changes in the environment caused by the fatigue of the processing conditions drift or deviation, quality characteristics may appear deviation. Determining the optimal process parameter settings is critical to the productivity, quality and production cost of the plastic injection moulding (PIM) industry. . In the past, trial-and-error methods or Taguchi's parameter design method were used to determine the optimal process parameter settings for PIM. However, these methods are not suitable for the current PIM [1-6] due to the requirements of complex production and multi-response quality characteristics.

This review article aims to the recent research in designing the mould and determining the various important process parameters of plastic injection moulding. For improvement of part quality, a number of research works based on various approaches have conducted in the domain of the parameter setting for injection moulding. These approaches, including nonlinear mathematical models, Taguchi method, Artificial Neural Networks (ANN), Genetic Algorithms (GA), Fuzzy logic, Finite Element Method(FEM), Response Surface Methodology,Grey Rational Analysis and Principle Component Analysis (PCA) are described in this review article. Effect of various parameters on the concern defects are also discussed.

Key words: Genetic Algorithms (GA), Finite Element Method(FEM),Non Linear Modeling, Response Surface Methodology, Grey Rational Analysis and Principle Component Analysis (PCA)

Introduction

Mainly in plastics injection moulding there are requirement of developing more efficient management system which can minimize the deficits of plastic manufacturing process. This study investigates information about the injection moulding of plasticparts and their process parameters used in the earlier studies. As a result, optimization of the parameters in PIM is important regarding minimizing various defects viz. shrinkage and warpage. Tuning of the parameters is not a new concept, but the parameters are different for different machines and products, so it is required to figure out balancing and optimality of their values every time during production process. Therefore, in this manner, some of the techniques like ANN, RSM, GA and combination of them are used to minimize defects in plastics products.

1.1 Role and importance of process parameters in plastic injection moulding

Injection moulding is widely used to make plastic parts because of its low cost, less commuting time, and excellent dimensional tolerances. In addition, there are some other advantages, such as light weight of parts and high surface finish of optional parts, which makes this process superior to other processes. In addition, plastic injection moulding is a very complicated process. One of the following situations will increase the defects of the object, such as improper mould design, improper material selection, and improper selection of the most important process parameters [7-9].

Object design and mould design are mainly carried out in the early stage of product development and cannot be easily changed directly. Therefore, the correct selection of process parameters is the only way to reduce defects and improve quality [10].In today's production system, 30% of plastic parts are manufactured by injection moulding. The correct selection of process parameters is called "black art" because it depends on the experience and prior knowledge of the machine operator and includes a trial and error process. Many researchers are working to eliminate expensive trial and error through various techniques [9, 11].

In injection moulding process there are mainly three stages: filling phase (packing phase), cooling phase and ejection phase. Cooling phase influences productivity and quality of the product. In injection moulding, there are many process parameters which depend on and controlled by the machine of plastic injection moulding [12]. At time of manufacturing, quality terms of object such as shrinkages such as shrinkage, warpage, weld lines, mould lines, flow marks, flash marks, sink marks, and void depend on upon process parameters which include [13-14]:

- Melt and Mould temp.
- Cooling time
- Cooling temp.
- Injection pressure
- Screw velocity in RPM
- Holding pressure
- Packing time etc.

1.2 Defects in plastic injection moulding

Plastic injection moulding is one of the important net-shape-forming processes for plastic material like thermoplastics. During this process some defect may occur like:

- Sink marks
- Shrinkage and Warpage

- Air voids
- Weld-lines
- Mould lines
- Flash &Flow marks

By proper selection of parameters, various defects can be avoided and removed with the suitable selection and optimization of PIM parameters[15].

Table Error! No text of specified style in document.**.1 Effect of Injection Moulding Parameters on Product Quality**

DEFECT	ADJUSTMENT FOR PARAMETER SETTINGS
Poor surface finish	➢ Increase injection pressure and speed ➢ Change shot size ➢ Increase melt temp. & mould temp.
Flash	➢ Reduce melt temp. and Inj. Press. ➢ Decrease cycle time ➢ Better mould venting ➢ Increased clamp pressure
Weld lines	➢ Increase injection press. ➢ Increase packing duration and pressure ➢ Increase melt temp. ➢ Increase mouldtemp.
Sinks or Voids	➢ Increase injection pressure ➢ Increase packing duration and pressure ➢ Increase melt temp. ➢ Decrease mouldtemp.
Warpage	➢ Increase mouldtemp. ➢ Increase injection pressure and velocity ➢ Increase packing duration and pressure

The value of shrinkage is different for different type of plastic materials, in some plastics, it may be zero and others it may little or in some, it may be higher in degrees. The value of tolerance in moulded parts is mainly determined by the predicted value of shrinkage rightly. It's hard to control and predictshrinkage because it is not isotropic always [16]. The amount of shrinkage is depending upon following causes:

- Uneven cooling
- Non-uniform volumetric shrinkage
- Anisotropic material behaviors
- Differential thermal strain

From Figure.**1**, its show effect of varies process parameters on shrinkage. Shrinkage is increased with increasing in melt temp., mouldtemp., and part thickness but in the case of increasing Holding pressure and packing duration it is decreasing. With increasing of injection rate the first shrinkage reduced, but slowly it is increasing.

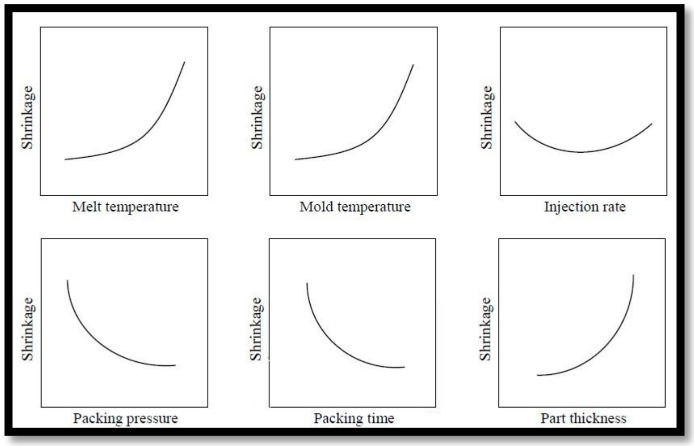

Figure.1 The Variation of Shrinkage Caused by Processing and Design Parameters[17]

Warping is due to differential shrinkage if two layers or part of the same object have a different amount of shrinkage than the object will warp. In other words, if there is variation in shrinkage, than warpage is there in plastic parts. Warpage is the part defect which originated by a non-homogenous change in internal stresses. It is due to imbalance following causes:

- Imbalance in mouldtemp.
- Imbalance in injection pressure due to this there is sudden changes in velocity
- Imbalance in Holding pressure due to this there is sudden changes in packing duration

Among all defect, warpage is considered to be one of the most difficult defects to control. There is one more reason for warping if one area over packed, and another one is less packed, due to which differential shrinkage occurs, and warpage is there [13, 15, 18-20].

1.3 Optimization methods in plastic injection moulding

Different researchers apply various methods for optimization. Reddy et al. [13] Mould flow simulation software and artificial neural network have been used to predict the warpage of plastic injection moulded parts. This research proposes a further extension by considering digital process parameters and output characteristics. Kamarudin et al. [14] Focusing only on Taguchi's method, the goal is the bending deflection of plastic pallets. L9 OA uses four process parameters at three levels. In this study, the melting temp., injection rate, cooling duration, and Holding pressure were studied. The results show that holding pressure is the main contribution of all parameters.

Several studies have revealed a combination of different optimization techniques; it will improve the effect of injection moulding. This combination of technologies is called a hybrid optimization system; Babur Ozcelik and Tuncay Erzurumlu [21] first used it in 2005. They combined response surface methods and genetic algorithms to find the effect of size parameters on warpage. Since each technology has its own advantages and disadvantages, hybrid technology is a good way to overcome this difficulty. It allows the advantages of each technology and discards their weaknesses. However, the best results can only be obtained by selecting the correct process parameters. In previous studies, researchers combined various optimization technologies such as Taguchi, RSM, GA, PSO, SA to improve the quality of plastic products.

Table 2.2 below summarizes the different research in the field of plastic injection moulding. The content includes the optimization methods used, parameter settings and research goals.

Table Error! No text of specified style in document.**.2 Summary of Optimization Methods in Plastic Injection Moulding**

Researcher	Method	Target	Parameter settings
➢ Reddy et al. [13]	➢ Mould flow ➢ ANN	➢ Warpage	➢ Mould temp. ➢ Melt temp. ➢ Holding pressure ➢ Packing time ➢ Cooling time
➢ Kamaruddin et al. [14]	➢ Taguchi	➢ Bending deflection	➢ Melting temp. ➢ Injection speed ➢ Cooling time ➢ Holding pressure
➢ Chen et al. [7]	➢ Taguchi ➢ Regression ➢ BPNN ➢ GA ➢ Hybrid PSO-GA	➢ Length ➢ Warpage	➢ Melt temp. ➢ Injection velocity ➢ Holding pressure ➢ Packing time ➢ Cooling duration
➢ Tang et al. [9]	➢ Taguchi	➢ Warpage	➢ Melt temp. ➢ Filling time ➢ Holding pressure ➢ Packing time
➢ Taghizadeh et al. [22]	➢ Mould Flow ➢ ANN	➢ Warpage	➢ Mouldtemp. ➢ Melt temp. ➢ Ejection Temp. ➢ ThermalConductivity
➢ Yin et al. [23]	➢ BPNN ➢ Fe simulation	➢ Warpage	➢ Mouldtemp. ➢ Melt temp. ➢ Holding pressure ➢ Injection pressure ➢ Packing time ➢ Cooling time
➢ Tzeng et al. [24]	➢ Taguchi ➢ BPNN ➢ GA ➢ RSM	➢ Ultimate strength ➢ Flexure strength ➢ Impact Resistance	➢ Nozzle temp. ➢ Melt temp. ➢ Holding pressure ➢ Packing time ➢ Mouldtemp.

➢ Mathivanan et al. [11]	➢ FFD ➢ RSM-CCD	➢ Sink depth	➢ Melt temp. ➢ Mouldtemp. ➢ Injection time ➢ Volume-to-pressure ➢ Switch Over ➢ Packing time ➢ Holding pressure ➢ Rib-to-Wall ratio ➢ Rib distance from gate
➢ Chiang et al. [25]	➢ RSM	➢ Shrinkage and warpage	➢ Mouldtemp. ➢ Packing time ➢ Holding pressure ➢ Cooling time
➢ Shi et al. [10]	➢ ANN ➢ Mould flow	➢ Warpage	➢ Mouldtemp. ➢ Melt temp. ➢ Injection time ➢ Packing time ➢ Holding pressure ➢ Cooling Time
➢ Chen et al. [26]	➢ Taguchi ➢ BPNN ➢ GA ➢ PSO	➢ Product length ➢ Warpage	➢ Melt temp. ➢ Injection velocity ➢ Injection pressure ➢ Holding pressure ➢ Packing time
➢ Guo et al. [15]	➢ FFD ➢ CCD	➢ Warpage	➢ Mouldtemp. ➢ Melt temp. ➢ Injection time ➢ V/P switch-over ➢ Holding pressure ➢ Packing time ➢ Coolant temp. ➢ Coolant Reynolds number
➢ Ozcelik et al. [21]	➢ Mould Flow ➢ GA ➢ RSM	➢ Warpage	➢ Dimensional parameters
➢ Sun et al. [27]	➢ RSM ➢ GA	➢ warpage	➢ Melt temp. ➢ Mouldtemp. ➢ Injection time ➢ Holding pressure ➢ Packing time
➢ Shen et al. [28]	➢ ANN ➢ GA	➢ volumetric shrinkage	➢ Melt temp. ➢ Mouldtemp. ➢ Injection time ➢ Packing time ➢ Holding pressure

➢ Ehsan et al. [29]	➢ RSM ➢ Simulated Annealing Algorithm	➢ Warpage; ➢ Shrinkage	➢ Melt temp. ➢ Mouldtemp. ➢ Injection pressure

1.4 Response Surface Methodology (RSM):-

In the field of mathematical statistics, response surface methodology (RSM) investigates the relationships between explanatory variables (an independent variable) and one or more than one dependent variable (also known as response variables). G. E. P. Box and K. B. Wilson in 1951 develop is a method. The main thought of RSM is to make use of predesigned sequence (runs) to conduct experiments to find the best response. Here is an example in which regression model for Copper content was determined by second order polynomial equation as shown in Figure 2.

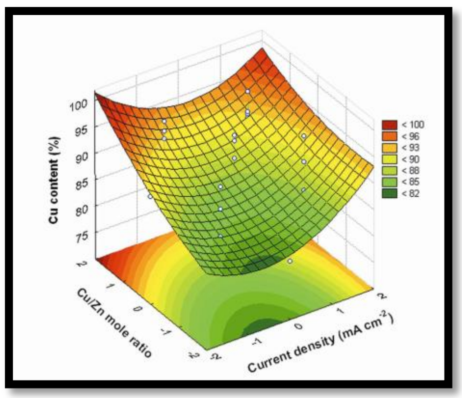

Figure2RSM Surface and Contour Plot of Copper Content (%) as a Function of Current Density and Cu/Zn Mole Ratio. [30]

Example: The regression model for Cu content (f_1) is stated by the subsequent second-order polynomial equation:

$$f_1(\%\ Cu\ content) = 66.32 + 4.21x_1 + 1.23x_2 + 0.62x_3 + 2.62x_4 + 1.15x_2^2 + 2.58x_3^2 + 3.13x_4^2 - 1.34x_1x_2 - 2.51x_1x_4 - 2.18x_2x_3$$

Developers suggested the use of second-degree (the sum of the power of the variables) polynomial model to do this. They accept that this model is the only estimation, but applying RSM model is simple to approximate and use, even the knowledge of the process is less. Steps for RSM are shown in figure 3.

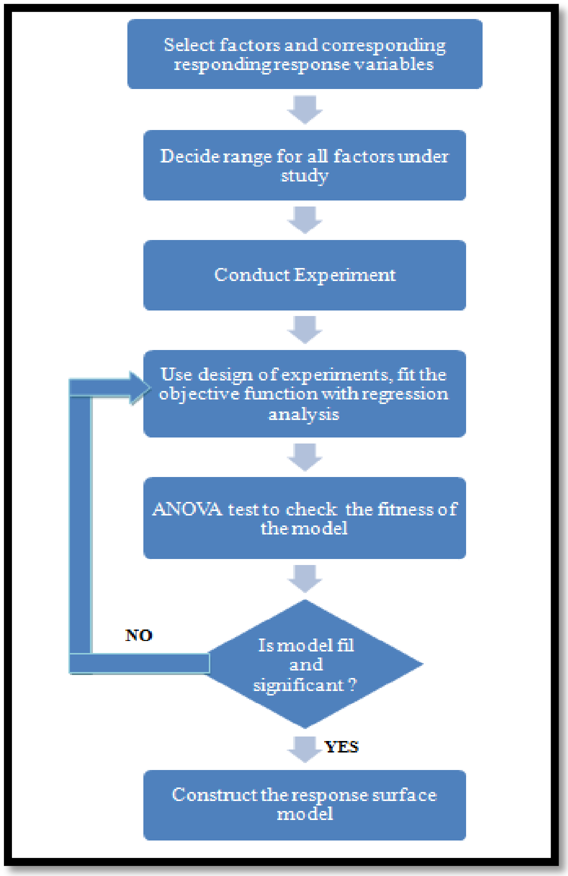

Figure.3 Steps in RSM

1.4.1 Central composite design

The second-order model can effectively and central composite design (CCD) (Montgomery, 1997) to build. CCD is a first order (2^N) designed to enhance tuning parameters by the additional central and axial points to let estimate of the second-order model. In the Figure 4, the factorial design involves 2^N points, 2^N axial points, and a center point. In CCD, 3^N presented to the second-order model construction design by reducing the number of experiments judge against to an FFD (15 experiments in the case of CCD, as compared to 27 for the full factorial design) instead. In the issue, a significant number of design variables under the circumstances, the experiment may be time-consuming, CCD even use.

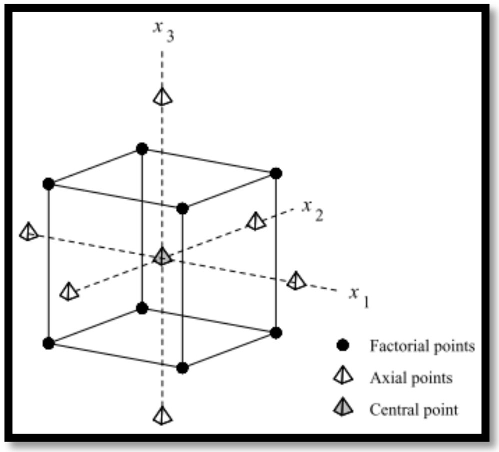

Figure.4 Modal Design of CCD for Three Design Variables at Second Level[31]

1.5 Genetic Algorithm (GA):-

1.5.1 Introduction

A genetic algorithm is a mathematical technique which based on "Natural Selection" of nature. This technique uses in many fields like artificial intelligence, optimization, and research problems. A genetic algorithm is belong to the evolutionary algorithms (ES). This algorithm gives a solution of the problem by using the natural evolution of mankind. In this algorithm, there are some stages like:

1. Representation (inheritance or population)
2. Selection (reproduction)
3. Crossover
4. Mutation

GA can apply to resolve problems even they are not well suited for the standard optimization problem, even in which objective function discontinued or higher nonlinear.

1.5.2 Various Steps involved in GA Procedure

➢ **Representation (inheritance or population)**

In GA each variable is first coded into a defined length of binary values (1 and 0) which calledas a set. This setfurther divided into N small sets as shown:

$$\underbrace{11010}_{x_1}\ \underbrace{1001001}_{x_2}\ \underbrace{010}_{x_3}\ldots\underbrace{0010}_{x_N}$$

➢ **Selection (reproduction)**

This is the first function which applied to the population. In this step, only good set out of population is selected and mark it as the mating pool. A goodset is referring to a set which is capable of generating best results. The main idea is to take above average sets to next level in the form of mating pool. The respite of them gets rejected at this level.

➢ **Crossover**

In this operation, two different sets are picked from the mating pool at random, and some part out of that one set exchangedfrom another set. In crossover both sets, which is called parent cut at the same place and the first half of sets exchanged and two new strings called as a childmade. As shown in

Figure5:

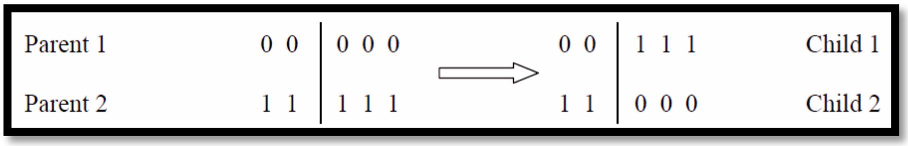

Figure5 Crossover

Childs, which is newlyconstructed sets, are much better than their parent sets if the suitable side was taken. This process is random because it's hard to knowproper side. Due to random side selection, the child sets some time may be not good than parent sets. In such cases, this type non-fit child created by crossover will not carry on in next reproduction.

- **Mutation**

In this operation sets created by crossover are alters locally to make better sets. The mutationoperation changes a1 to a 0 and vice-versa with small probability P_n for example:

0 0 0 0 0 ⟹ 0 0 0 1 0

The main need of mutation is there due to create some diversity.

After applying all steps on complete population, one generation of GA is completed. These steps are applied again and again depend on generations are decided [32,33]. Various steps in Genetic Algorithm- GA's steps are shown if figure 6.

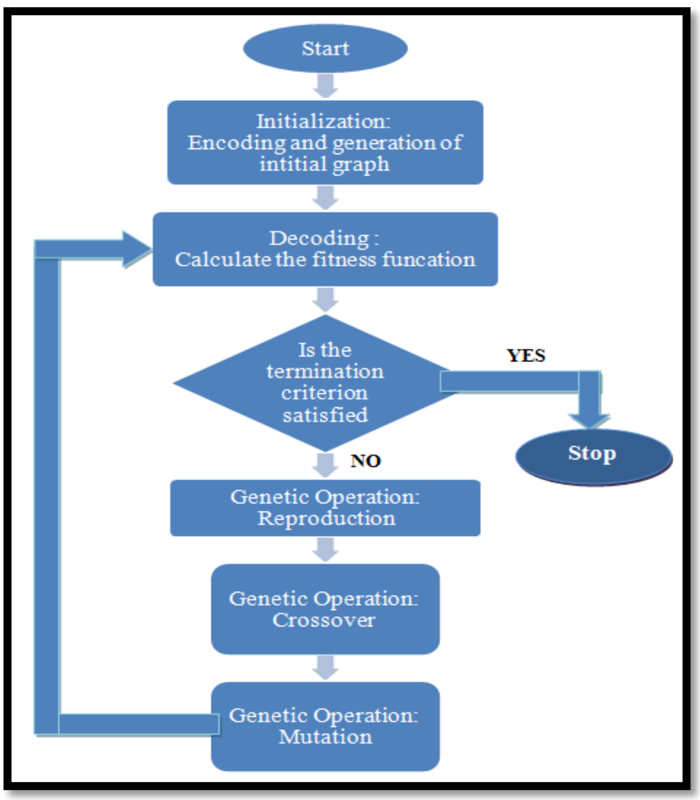

Figure.6 Flow Chart of Genetic Algorithm

Conclusion:

This article purposes to review recent research in the design and determination of injection moulding process parameters. Many research works based on different approaches have been carried out in the field of parameterization of injection moulding. These approaches, including mathematical models, the Taguchi method, artificial neural networks (ANN), fuzzy logic, genetic algorithms (GA), the finite element method (FEM), nonlinear modeling, the methodology of response surface, linear regression analysis, gray rational analysis and principle component analysis (PCA) has been described in this article. These approaches gives user to better tuning the injection moulding parameters and thus to enhance the part quality and productively.

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