Prediction of Process Parameters of New Injection Molding Products Based on Historical Qualified Product Data

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Abstract. In the field of thermoplastic injection molding, there are a large number of qualified product data, mining and analyzing these data is of great significance to enterprise production. At present, most scholars do optimization research around given process parameters, and cannot fundamentally solve the problem of process parameter setting values. To this end, this article proposes a new method, through the analysis of the material, structure and process of historical qualified products, from the perspective of the product, find the factors that affect the process parameters, and use the BP neural network model to train the non-linear mapping relationship between the product and several main process parameters, and predict the main process parameter values of the new product. For inexperienced manufacturers of injection products, this method can greatly improve their productivity.

Keywords. Injection molding; product structure; process parameters; BP neural network.

1. Introduction
As people’s demand increases, more diverse plastic injection molding (hereinafter referred to as injection molding) products lead to faster product updates and shorter production cycles. Therefore, in the development process of injection molding products, timely determination of injection molding process parameters is particularly important for the quality of new products and whether they can enter the market in advance. The traditional method of determining process parameters usually relies on statistics and the experience of designers [1, 2]. Due to the non-linear mapping relationship between various process parameters and quality goals, it is difficult to obtain the optimal process forming method only relying on the experience of the designer [3].

Li et al. in order to reduce the warpage of the transparent parts of the multi-cavity mold, an optimization technology combining orthogonal experiment, Kriging model and optimization algorithm is proposed to optimize the injection molding process parameters [4]. Dong et al. proposed an intelligent injection molding model with parameter self-learning optimization [5]. Saad et al. proposed a framework for determining the optimum injection molding process parameters for minimized product defects through experimental-based multi-objective optimization [6]. The above methods are based on optimization research of given parameters and have certain limitations in actual production applications. Therefore, this article proposes a new method, based on the historical data of qualified products, through the analysis of the material, structural characteristics and process of the injection product, find the characteristic variables of the product itself as the influencing factors of the process parameters, these influencing factors are used as the input of the BP neural network model, and several main process parameters are used as the output. The training model enables it to quickly and accurately predict the injection molding process parameters of the new product.
2. Injection Product Analysis
The determination of the process parameters of injection molded products largely depends on the material and structural characteristics of the product itself [7]. Analyze the material and structure of the product, and use 6 performance indicators to describe the product material, 2 numerical indicators to describe the mold cavity and 1 functional indicator to describe the 3D model of the product. The product process is analyzed, and 7 main injection molding process parameters are selected as the research object.

2.1. Material Analysis of Injection Products
Table 1 lists three commonly used materials and their measurement performance indicators.

| Material Name | Relative Density | Elasticity Modulus (GPa) | Compression Strength (KPa) | Shrinkage Rate (%) | Poisson Ratio | Thermal conductivity (W·(mK)^-1) |
|---------------|------------------|--------------------------|---------------------------|--------------------|--------------|---------------------------------|
| ABS           | 1.05             | 2.20                     | 69                        | 0.3~0.8            | 0.3940       | 0.25                            |
| PC            | 1.20             | 2.32                     | 78                        | 0.5                | 0.3902       | 0.21                            |
| PP            | 0.90             | 0.89                     | 45                        | 1.0~2.5            | 0.4203       | 0.23                            |

It is not difficult to see that differences in product materials will cause changes in various performance indicators, which will inevitably lead to changes in injection molding process parameters. Therefore, the material properties of the product can be described according to the material performance indicators of the injection molded product, and the six numerical performance indicators of relative density, elasticity modulus, compression strength, shrinkage rate, Poisson ratio and thermal conductivity can be used as the description of the injection product material.

2.2. The Structural Characteristics Analysis of Injection Products
Injection products are usually divided into three categories: large injection products, precision injection products and thin-wall injection products. Thermoplastic injection molds mold can be subdivided into five types: standard molds, laminated molds, hot runner molds, cold runner molds and special design molds [8]. Even after the products are classified by the above categories, the shape is still complicated. The shape matching method is an effective 3D model retrieval method in the face of complex shapes [9]. It constructs a shape function by measuring the distance between two random points on the surface of a 3D model, and performs 'uniform sampling' of the shape function as sample points to compare the similarity of the model. The method of using shape function to describe the 3D model of the product adds a feasible theoretical basis for this article.

But only describing the 3D model of the product is not complete enough for injection molded products, because the initially molded product contains residual material, so the parting surface and flow gate position parameters are introduced to roughly describe the structure of the product in the cavity. Specifically, the area of the parting surface and the maximum linear distance from the flow gate to a certain point on the product (the farthest pouring distance) are taken into account as the description parameters of the product’s characteristics in the mold cavity.

In order to describe the structure information of injection molded products as completely as possible during injection molding, taking into account the structure of the injection product in the mold, the data is finally classified by product category and mold type. The parting surface area, farthest pouring distance and shape function of the product are used to express the structure of the injection molded product in the classified data set.

2.3. Analysis of Injection Molding Process
Existing studies have shown that injection molding process parameters have an impact on product quality [10], so the whole process of injection molding process can be analyzed, and the process
parameters that have a significant impact can be selected as the research object of this article. The injection molding process mainly includes three parts: preparation before injection, injection molding process and post-processing. The plastic injection molding process is shown in figure 1.

![Plastic Injection Molding Process Diagram](image)

**Figure 1.** Plastic injection molding process diagram.

In the preparation stage before injection, the main process variable is the preheating part, that is, the selection of temperature of the mold cavity. In the injection molding process, the melt temperature, the injection pressure and injection time during the injection process, the holding pressure and holding time after injected, and the final cooling time in order to eliminate the heat and stress of the product, will have a great influence on the final quality of the product. The process variables in the post-processing stage are used to improve the output quality, but not every product has the same post-processing process, and the post-processing process is based on the product quality meeting the requirements, so the process variables at this stage are not considered as factors that affect product quality during the injection molding process.

Through the analysis of the whole process of injection molding, the 7 main process parameters of injection molding can be considered: cavity temperature, melt temperature, injection time, holding time, cooling time, injection pressure and holding pressure.

3. **Data Preparation**

The nature of the injection molding industry determines that most of the data is stored inside the enterprise. In order to obtain a relatively balanced data set, it is necessary to investigate multiple companies to extend the breadth of the data set, which is very important for the prediction of the BP neural network model. The structured processing and feature dimension processing of these data are used as preparation data for neural network training. The data preparation process framework is shown in figure 2.

![Data Preparation Process Framework](image)

**3.1. Data Structure Processing**

The analysis in the second section shows that the raw data can be divided into 15 categories through 3 product categories and 5 mold types of injection products. For possible data anomalies, data inconsistencies, and missing data in each type of data set, it can be solved by using cleaning preprocessing algorithms such as smoothing filtering or judging the correct parameters based on expert experience. After processed, complete and high-quality data of various parameters can be obtained.
3.2. Data Dimension Processing

Due to the inconsistent dimensions of product description features in the above data, it is necessary to reduce the dimensionality of each data before it can be used as the input and output of the neural network.

Numerical data such as product material performance indicators, mold cavity characteristic values and product process parameters are all one-dimensional values, so dimensionality reduction is not required.

For two-dimensional data such as the shape function describing the 3D model of the product (figure 3a), in order to describe it with a discrete one-dimensional vector, the function is sampled by a fixed step size method of 4% of the maximum value of the abscissa (distance value), each ordinate (probability value) of the sampling point is taken as a sample value, and use the value of the maximum distance point on the abscissa of the function as the maximum distance. Therefore, the shape function can be described discretely by a maximum distance value and 25 sample values (figure 3b).

Figure 2. Data preparation process framework.

Figure 3. A product shape function (a) and its sampling (b).
In order to eliminate the inconsistency of the various numerical vector units in the data and improve the accuracy of model prediction, the above-mentioned numerical vectors need to be processed without dimension. The processing formula is as in equation (1).

\[ P_i = \frac{x_i - \min(x_i)}{\max(x_i) - \min(x_i)} \]

where \( P_i \) represents the processed parameter, \( x_i \) represents the true value of a parameter, \( \min(x_i) \) represents the minimum value of the parameter in the data set, \( \max(x_i) \) represents the maximum value of the parameter in the data set. It is worth noting that the sampling values of the shape function are all probability values (between 0 and 1), which are dimensionless and do not need to be processed.

4. Prediction of Product Process Parameters Based on BP Neural Network

The injection molding process is a complex engineering problem, and there is an inseparable relationship between the product model and the process parameters. Dealing with this nonlinear, multi-objective complex function relationship is exactly what the black box model of neural network is good at. Based on the prepared data, it is assumed that the 34-16-16-7 BP neural network model is established, and the process parameters of the new product are predicted by learning from a large amount of historical qualified product data.

4.1. BP Neural Network Construction

The 34 dimensionless description parameters of the product in the previous section are used as the input of the neural network, and the 7 dimensionless process parameters of the product are taken as the output. According to the empirical formula, the number of hidden layer nodes is determined to be within the scope of 7-16, it is assumed that a double-hidden-layer BP neural network model with 16 nodes is chosen to be established. The network topology of the model is shown in figure 4.

4.2. BP Neural Network Training

Since the quality of injection molded products is affected by various process parameters with different coefficients [11], the error of each output is calculated by the root mean square, when setting the total error function, as in equation (2), consider adding the influence weight \( \lambda \) of each output on product quality.

\[ total\_error = \left( \sum_{i=1}^{7} \lambda_i \left( y_i^* - y_i \right)^2 \right)^{1/2} \]

where \( \lambda_i \) represents the weight of the i-th output parameter, \( y_i^* \) is the expected output of the i-th parameter, and \( y_i \) is the actual output of the i-th parameter.
According to the nonlinear function relationship between the input variable and the output variable, select the unipolar S-type excitation function to calculate the output of each layer. Through the calculation of the error, the gradient descent method is used to backpropagate to adjust the weight and bias. Set a certain learning efficiency η, the model is continuously trained, and finally the total error is less than a given value to complete the training.

4.3. BP Neural Network Prediction
For the trained model, the output is a dimensionless value in the range of 0-1, and these dimensionless values need to be converted into the true values of the process parameters. The new product model feature description vector is input into the trained model to predict the value of process parameters, and the accuracy of the prediction can be tested according to the simulation method. There is also a method to test the accuracy of the model by using the N-fold cross-validation (usually a 5-fold) on a certain type of data set to train the model and test the accuracy of the model prediction.

5. Conclusions
Based on the analysis of the injection product itself and process parameters, this article classifies the qualified product history data according to the product categories and the mold types, proposes to use the product material, product mold cavity and shape function to represent the product, and use BP neural network to learn the non-linear mapping relationship between products and several main process parameters, and finally the neural network model is trained to predict several main process parameters of the new product. This prediction method is superior to traditional empirical methods in the selection efficiency of product process parameters, and it can show great application value in the face of inexperienced enterprises.

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