Overview of injection molding process optimization technology

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Abstract. Injection molding process parameters have a very important influence on the molding quality of plastic parts. In this paper, the application of injection molding parameter optimization technology in the study of injection molding process is reviewed. The basic principles and characteristics of various optimization techniques are described. Optimization techniques mainly include: Optimization based on Taguchi method, Optimization of numerical simulation based on CAE technology, Optimization based on genetic algorithm, Optimization based on artificial neural network. The application types of optimization problems applicable to various optimization techniques are discussed.

1. Introduction
Injection molding is one of the most widely used molding processes in the plastic industry. It can produce a variety of complex structure, precise size of products, widely used in aerospace, mechanical electronics, medical and instrumentation and other fields. There are many factors affecting the quality of injection molding. It mainly include four aspects: raw materials, injection machine, mold structure and injection molding process parameters[1]. The main process parameters include injection pressure, injection time, injection speed, packing pressure, mold temperature, melt temperature, cooling time and so on. Injection molding is a complex multi-variable, nonlinear and time-varying unsteady process, which makes it more difficult to optimize the process parameters. In recent years, researchers have done a lot of researchs on the optimization of injection molding process parameters in order to improve the molding quality of products. In this paper, the research status of the main injection molding process parameter optimization technology is summarized.

2. Optimization based on Taguchi Method
Taguchi method[2] was proposed by Dr. Taguchi from Japan. It is an efficient method that can be designed to be robust and optimize operation under changeable environmental conditions. The basic idea is that the orthogonal table is used to arrange the test scheme, and the signal-to-noise ratio(S/N) is taken as an index to measure the robustness of product quality. It try to achieve the comprehensive effect of technology and economy with the lowest cost and the best quality[3]. Taguchi optimization method is simple, practical and effective. It is widely used in injection molding technology.

Hentati[4]and others conducted orthogonal experiment of four factors and three levels on PC/ABS blends by Taguchi method. The effects of injection pressure, melt temperature, mold temperature and other technological parameters on the residual stress and shear stress of the parts were analyzed. The process parameters were optimized to obtain PC/ABS parts with lower shear stress and no injection defects. Park[5] and others described the rheological behavior of raw materials by using the non-
newtonian viscosity model based on Taguchi method and the minimum experimental set theory. The effects of materials and process conditions (powder size, injection temperature, initial powder volume fraction and shear rate) on the separation of powder and binder were studied by torque rheometer experiment. Li[6] and others studied the effects of technological parameters such as fiber content, fiber aspect ratio, melt temperature, injection pressure, packing pressure and filling time on the performance of fibre-reinforced ABS composite materials by using orthogonal experimental design. Finally, particle swarm optimization (PSO) and genetic algorithm (GA) are used to find the minimum change value of fiber direction tensor, which improves the quality index of local fiber direction tensor. In terms of fiber reinforced PA66 materials, Liu Chuntai[7] and others designed the L9 experimental matrix by using Taguchi method, and analyzed the influence of injection pressure, melt temperature, injection rate, packing pressure and other process factors on the tensile strength of injection parts with and without weld lines by using the standard variable analysis method. The optimal tensile strength and technological conditions were predicted. The predicted results were consistent with the experimental results. Liu[8] and others designed the L18 orthogonal test for the six process parameters by using the experimental matrix design method in view of the weld mark strength of injection parts. The strength of fusion mark of plastic parts was improved by optimizing the coefficient of fusion joint.

Taguchi method is based on the orthogonal experimental design theory and by means of S/N analysis and experimental verification. It is widely applied to various optimization problems in injection molding process. Taguchi method combined with simulation software can effectively improve the accuracy of orthogonal design and optimize efficiency.

3. Optimization of numerical simulation based on CAE technology

Injection molding CAE technology is based on plastic processing rheology, heat transfer, finite element method, computer graphics and other basic theories, the establishment of plastic melt flow in the mold cavity, pressure retention, cooling process, heat transfer of the physical and mathematical model. The numerical calculation theory was used to construct the solution method, and the simulation analysis of the forming process was carried out, so as to predict the occurrence of forming defects such as warpage, shrinkage and weld line of the plastic parts. It provides scientific basis for designers to optimize mold design and process parameters[9]. Optimization of numerical simulation refers to the use of injection molding simulation software (Moldflow, Moldex3D, HsCAE, etc.) to carry out numerical calculation of molding schemes with different injection molding process parameters. Through the evaluation and comparison of simulation results, an optimal combination of process parameters was obtained [10].

Zhao Huijuan[11] and others analyzed the structure of the air conditioning housing bracket, analyzed the gate position with the help of Moldflow software, and determined the pouring system. The injection velocity curve, pressure preserving curve and cooling process parameters of multi-stage screw were optimized. Mi Libo[12] and others used Moldflow simulation platform software to simulate the injection molding of the PP remote control shell. The influences of gate location, number and gate cross-sectional area on the warpage of the workpiece were mainly evaluated.

This method attempts to calculate the relationship between process parameters and product quality through simulation of injection molding simulation software. The accuracy of the optimization results depends on the accuracy of the simulation software, so there are errors in the simulation results. In order to reduce the influence of simulation error, the model needs to be further analyzed with experimental design and other auxiliary techniques. It provides a solution for the optimization of process parameters qualitatively and quantitatively and reduces the dependence on the simulation results. Zhu Junjie [13] and others used CAE software to establish a numerical model for the injection molding of the internal storage of automobiles. Five injection molding process parameters were selected as influencing factors, the warpage and shrinkage mark index of the storage box were taken as optimization indexes. The multi-objective optimization could be converted into single objective Optimization based on the combination of Grey-Taguchi. The optimum combination of process
parameters with two objectives was obtained. Through simulation verification, the warpage was reduced by 9.25%, and the shrink mark index was reduced by 33.42%.

### 4. Optimization based on genetic algorithm

Genetic algorithm (GA) was proposed by Professor Holland of the University of Michigan in 1969. It is a kind of self-organizing and adaptive artificial intelligence technology which simulates the biological evolution process and mechanism in nature to solve extremum problems. It is an algorithm that simulates the genetic mechanism of nature and the evolution of biology to form the optimal solution. GA is suitable for solving complex nonlinear and multidimensional space optimization problems [14].

Zhou Xiang [15] and others established the approximate functional relationship between process parameters and warpage value by using Kriging agent model and experimental design. GA is applied to global optimization of process parameters to obtain the combination of process parameters with the minimum warpage value. On the basis of optimization design, the influence of various process parameters on warpage was studied by proxy model prediction function. Liu Donglei [16] and others took vehicle-mounted high-light bluetooth products as an example and used the method of both molding test and numerical simulation to obtain test sample data. Through entropy weight method, response surface method and variance analysis, a comprehensive quality prediction model of RHCM products was established. Finally, the improved genetic algorithm (IGA) was used to realize the optimization process of quality prediction model, which provided a feasible process planning technology for the formulation of RHCM molding process. Young [17] and others took advantage of the genetic algorithm's ability to deal with nonlinear problems. Taking the resin transfer molding process of plastic parts as an example, GA was used to optimize the design of gate location and number of plastic parts. At the same time, the technological parameters were optimized. Much better optimization results were obtained.

GA is a search algorithm based on natural selection and genetic mechanism [18]. GA has the characteristics of parallelism and robustness. It can evaluate multiple points simultaneously in a complex search space, and only a few structures need to be detected to reflect a large number of areas in the search space. It is helpful to find the global optimal solution in the multi-value space. It is very suitable for solving uncertain problems or nonlinear complex problems, so it is widely used in nonlinear injection molding process.

### 5. Optimization based on artificial neural network

Artificial Neural Networks (ANN) is a theoretical mathematical model constructed artificially on the basis of human's understanding of brain Neural Networks. It can realize certain functions [19]. ANN technology has nonlinear characteristics, a large number of parallel distribution structure and learning and induction ability. It is very suitable for solving the nonlinear problem of injection molding. Huang Wei [20] took the 2mm standard tensile specimen as the analysis object, melt temperature, mold temperature, injection pressure, injection time and cooling time were taken as input layer, while shear modulus and warpage value were taken as output layer. BP neural network algorithm was used to optimize the injection molding process parameters, and the optimal process parameter combination was obtained. Melt temperature was 251°C, mold temperature was 46°C, injection pressure was 176Mpa, injection time was 0.42s. Ji Ning [21] and others took the volume shrinkage rate and shrinkage mark index of the lower cover of the charging treasure as the optimal control objectives, and took mold temperature, melt temperature, pressure holding time, pressure holding pressure and cooling time as the test factors. The optimal Latin hypercube test design method was used to obtain the test samples. The RBF neural network model between the test factors and the optimal control objectives was constructed. The predicted value of control target was optimized.

Li Xuejuan [22] and others took headlamp masks as the research example, the geometric size is 138.09mm×121.55mm×59.59mm, and the wall thickness is 2.5mm. Based on the forming process parameters, a multi-objective optimization model of weld line was established. The experiment was
designed by Taguchi method. The HNN samples were obtained by using Moldflow software. Finally, based on Pareto dominance theory, an IMOPSO algorithm was proposed to optimize the length and meeting Angle of weld line of injection parts. Wang Bo[23] and others took laptop battery cover as an example, the plastic injection molding simulation software was used to simulate the battery cover for 9 times. BP neural network, grey theory and genetic algorithm were combined effectively by the optimal weight coefficient. Three combination prediction models were established. Finally, the accuracy of the combined prediction method was verified by the actual manufacturing of the battery cover. ANN technology has nonlinear characteristics, strong adaptability, fast response ability and real-time learning. It has become an important optimization technique in parameter optimization field.

6. Conclusion
Injection molding process is a complex process with multiple physical fields and multiple factors influencing each other. Optimization of injection molding process parameters is an important means to prevent or improve molding defects and improve molding quality. Taguchi optimization method is simple, practical and effective in obtaining optimized process parameters by means of orthogonal test. The optimization of CAE technology numerical simulation is based on the simulation software. Through the evaluation and comparison of simulation results, a better combination of process parameters is obtained. Genetic algorithm has implicit parallelism and efficient use of local information, and it is easy to obtain the optimal solution. Artificial neural network technology has nonlinear characteristics, strong adaptability and fast response ability. The combined application of optimization techniques can make use of their respective advantages, make full use of advantages and avoid disadvantages, improve search efficiency and obtain the global optimal solution.

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References
[1] Mok, S.L., Kwong, C.K. (2002) Application of artificial neural network and fuzzy logic in a case-based system for initial process parameter setting of injection molding.J. Journal of Intelligent Manufacturing, 13:165-176.
[2] Peace, G.S. (1993) Taguchi Methods. Addison-Wesley, New York.
[3] Zeng, F.Z., Zhao, X. (2003) Taguchi method and standardized design.J. Standardization and Quality in the Machinery Industry, 11:7-9.
[4] Hentati, F., Hadriche, I., Masmoudi, N. (2019) Optimization of the injection molding process for the PC/ABS parts by integrating Taguchi approach and CAE simulation.J. The International Journal of Advanced Manufacturing Technology, 104:4353-4363.
[5] Park, D.Y., Shin, S.D., Cho, H. (2017) Effects of material and processing conditions on powder-binder separation using the Taguchi method.J. Powder Technology, 7:369-379.
[6] Li, K., Yan, S.L., Pan, W. F. (2017) Optimization of fiber-orientation distribution in fiber-reinforced composite injection molding by Taguchi, back propagation neural network, and genetic algorithm-particle swarm optimization.J. Advances in Mechanical Engineering, 9:1279-1290.
[7] Liu, C.T., Shen, C.Y. (2004) The Taguchi method was used to optimize the fiber reinforced plastic injection weld line tensile properties of PA66.J. Journal of Composite Materials, 5:68-73.
[8] Liu, S., Wu, J., Chang, J. (2001) An experimental matrix design to optimize the weldline strength in injection molded parts.J. Polym Eng &Sci, 40:1256-1262.
[9] Xie, P.C., Yang, W.M. (2008) CAE Theory and Application of Polymer Injection Molding. Chemical Industry Press, Beijing.
[10] Zhou, H.M., Gao, H., Zhang, Y. (2016) Automatic setting and optimization of injection molding
[11] Zhao, H.J., Yin X.D. (2019) Application of moldflow in optimizing injection molding process of air conditioning shell bracket. J. Journal of Jilin University of Chemical Technology, 36:24-29.

[12] Mi, L.B., Zhang, X.B. (2020) Optimization and application of injection molding gate design based on CAE simulation. J. Synthetic Resins and Plastics, 37:73-76.

[13] Zhu, J.J., Huang, W.H., Zhang, Q.R., et al. (2019) Multi-objective Optimization of Car's Built-in Storage Box Injection Molding Process Parameters Based on Grey-Taguchi Method. J. Plastic Science and Technology, 47:63-68.

[14] Ge, J.K., Qiu, Y.H., Wu, C.M. (2008) A review of genetic algorithm research. J. Computer Application Research, 10:2911-2916.

[15] Zhou, X., Chen, W.L., Wang, X.H. (2015) Warpage optimization of injection parts based on Kriging agent model and genetic algorithm. J. Journal of Plastic Engineering, 22:142-147.

[16] Liu, D.L., Shen, C.Y., Liu, C.T. (2011) RHCM Molding Process Optimization based on Response Surface Method and Improved Genetic Algorithm. J. Journal of Mechanical Engineering, 47:54-61.

[17] Young, W.B., Yu, H.W. (1997) Optimal design of process parameters for resin transfer molding. J. Journal of Composite Materials, 31:1113-1140.

[18] Chen, J.A., Guo, D.W., Xu, N.P. (1998) A review of theoretical research on genetic algorithm. J. Journal of Xidian University, 25:363-368.

[19] Zheng, S.R., Xin, Y., Yang, G.T., et al. (2003) Research method of injection molding parameter optimization. J. China Plastic, 4:3-9.

[20] Huang, W., Qian, Y.P., Gao, Q. (2019) Optimization of composite injection molding process based on BP neural network. J. Journal of Hubei University of Technology, 34:18-21.

[21] Ji, N., Zhang W.X., Yu Y.Y., et al. (2020) Quality control and prediction of injection molding based on radial basis function neural network and multi-island genetic algorithm. J. Engineering Plastics Applications, 48:62-68.

[22] Li, X.J., Shi, J.R., Yang, C.X. (2016) Multiobjective optimization of weld mark quality of injection molded parts based on IMOPSO method. J. Journal of Plastic Engineering, 23:173-179.

[23] Wang, B., Cai, A.J., Meng, G.H., et al. (2020) The combination algorithm is used to predict the warping deformation of injection molded products. J. Journal of Xi'an Jiaotong University, 8:1-8.