Simulation Modelling Practice and Theory 41 (2014) 15–27

Contents lists available at ScienceDirect

Simulation Modelling Practice and Theory

journal homepage: www.elsevier.com/locate/simpat

General frameworks for optimization of plastic injection molding process parameters

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A R T I C L E   I N F O

Article history:
Received 10 May 2013
Received in revised form 26 September 2013
Accepted 1 November 2013
Available online 1 December 2013

Keywords:
Injection molding
Process parameter optimization
Optimization methods
Simulation-based optimization

A B S T R A C T

Plastic injection molding is widely used for manufacturing a variety of parts. Molding conditions or process parameters play a decisive role that affects the quality and productivity of plastic products. This work reviews the state-of-the-art of the process parameter optimization for plastic injection molding. The characteristics, advantages, disadvantages, and scope of application of all of the common optimization approaches such as response surface model, Kriging model, artificial neural network, genetic algorithms, and hybrid approaches are addressed. In addition, two general frameworks for simulation-based optimization of injection molding process parameter, including direct optimization and metamodeling optimization, are proposed as recommended paradigms. Two case studies are illustrated in order to demonstrate the implementation of the suggested frameworks and to compare among these optimization methods. This work is intended as a contribution to facilitate the optimization of plastic injection molding process parameter.

1. Introduction

Molding conditions or process parameters play an important role for the plastic injection molding. The quality of the molded part including strength, warpage, and residual stress is greatly influenced by the conditions under which it is processed. Molding conditions also affect the productivity, cycle time, and energy consumption of the molding process. Molding conditions have a close relationship with other factors such as materials, part design, and tooling, which determine the quality of the plastic products. Molding conditions comprise the following important parameters [1]: melt temperature, mold temperature, fill time, packing time, and packing pressure.

The quality of a given molded part depends not only on the plastic material properties but also on the process parameters. Optimum process parameters reduce the cycle time and increase the quality of the product. In practice, setting the process parameters is mainly based on the experience of the plastic engineer. This method does not always ensure appropriate values of process parameters. Because the plastic exhibits a complex thermo-viscoelastic property, setting a proper molding condition that obtains a desired product quality is a challenge. As the result, the process parameters are often selected from hand books and are then adjusted subsequently by the trial-and-error method. It can be seen that trial-and-error method is costly and time-consuming.

For the analytical approach, a number of mathematical equations have been developed for deriving proper process parameters of injection molding [2]. However, they generally cannot always satisfy a reliable solution due to the complexity of the injection process when many simplifications are involved in the analytical equations. Therefore, many researchers have made great effort to find the methods for optimizing molding process parameters.

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1569-190X/$ - see front matter
http://dx.doi.org/10.1016/j.simpat.2013.11.003

Although there is a considerable amount of publications that focused on injection molding process parameters optimization, some of them still sound academic and are difficult to apply to practice. Furthermore, there have been no comparisons, assessment about the scope of application as well as review of the strong points and weaknesses of optimization methods. The selection of optimization method mainly depends on experience and subjective choice of each author. Therefore, analyzing the characteristics and the scope of application of existent optimization methods is a significant task. Moreover, finding appropriate general frameworks that facilitate the optimization of process parameters in injection molding is necessary.

2. Theoretical background and survey of the injection molding process parameter optimization

2.1. Optimization techniques

If we classify the numerical optimization technique, which is based on the way of improving the design point after each iteration, there are three kinds of optimization techniques: non-gradient-based, gradient-based, and hybrid optimization techniques. They are described briefly as follows:

Non-gradient based optimization techniques do not require an objective function, $f(\mathbf{x})$, to be differentiable because the algorithms do not use derivatives of $f(\mathbf{x})$. Examples of non-gradient-based optimization techniques are adaptive simulated annealing, Hooke-Jeeves direct search, and genetic algorithm (GA). These optimization techniques tend to reach a global optimum but require the huge number of function evaluations. GA is a well-known non-gradient based optimization technique. It is a stochastic search or optimization algorithm that mimics Darwin's theory of biological evolution.

Gradient-based techniques define the search directions by the gradient of the function at the current point. In practice, there are many kinds of gradient-based optimization techniques such as generalized reduced gradient, conjugate gradient, method of feasible directions, mix integer optimization, sequential linear programming, sequential quadratic programming, and Davidon–Fletcher–Powell. Gradient-based techniques, in general, give a quick convergence, but they may require a long run when the number of variables increases. Gradient-based techniques can also get risk of local extremum for high nonlinear optimization problem.

Hybrid optimization techniques use the combination of both non-gradient based and gradient-based techniques subsequently in order to take the advantages and reduce the disadvantages of single optimization technique. Presenting all of these optimization techniques is beyond the scope of this paper.

2.2. The common optimization methods

The terminology optimization method used in this paper refers to whether or not the explicit objective functions are formulated. For simulation-based optimization, the objective functions are often in the form of implicit equations. The value of the objective function is unknown until simulation results are obtained. There are two approaches that are used to resolve the optimization problem including direct optimization and metamodel-based optimization methods as shown in Fig. 1. The detail of these two optimization methods is described as follows.

2.2.1. Direct optimization methods

Direct numerical optimization is an approach that explicit objective functions are not required. Both gradient-based optimization techniques and non-gradient based optimization techniques can be applied to solve the optimization problem. Sometimes, direct optimization methods combine the GA and other optimization techniques. It is well known that GA tends

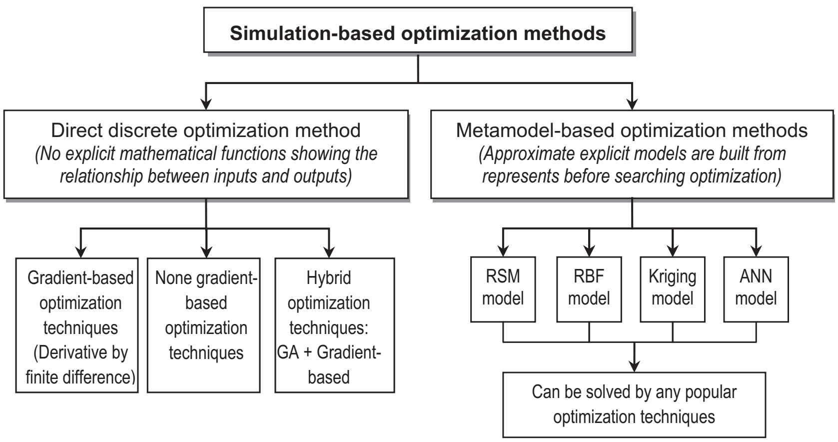

Fig. 1. Classification of optimization methods.