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Optimization of injection molding process for car fender in consideration of energy efficiency and product quality

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Abstract

Energy efficiency is an essential consideration in sustainable manufacturing. This study presents the car fender-based injection molding process optimization that aims to resolve the trade-off between energy consumption and product quality at the same time in which process parameters are optimized variables. The process is specially optimized by applying response surface methodology and using non-dominated sorting genetic algorithm II (NSGA II) in order to resolve multi-object optimization problems. To reduce computational cost and time in the problem-solving procedure, the combination of CAE-integration tools is employed. Based on the Pareto diagram, an appropriate solution is derived out to obtain optimal parameters. The optimization results show that the proposed approach can help effectively engineers in identifying optimal process parameters and achieving competitive advantages of energy consumption and product quality. In addition, the engineering analysis that can be employed to conduct holistic optimization of the injection molding process in order to increase energy efficiency and product quality was also mentioned in this paper.

Keywords: Multi-objective optimization; Injection molding process; Energy efficiency; Plastic car fender

1. Introduction

Injection molding has been the most popular method for making plastic products due to high efficiency and manufacturability. The injection molding process includes four important stages: filling, packing, cooling, and ejection. A primary traditionally concern in injection molding has been that of the extent to which high-quality products with strong mechanical properties can be manufactured, in the absence of any undesired defects. Many previous studies have sought to eliminate defects in plastic products. To minimize temperature deviation for an automotive product, cooling circuit parameters were optimized using CAE program [1]. In the case of reducing warpage, the combination of the response-surface method or neural network with a genetic algorithm was conducted in order to obtain optimal parameters [2, 3]. The deficiency of these studies was the lack of consideration for the energy consumption of the injection molding process. Consumer pressure, rising energy cost and environmental legislation have combined to increase the importance of reducing energy consumption in the industrial plastic industry.

To enhance practical application, both energy consumption and product quality should be taken into consideration. Energy saving for the injection molding process can be divided into two sub-aims. In the first sub-aim, companies and manufacturers focus on machine improvement and manufacturing technologies related to injection molding machine hardware and auxiliary equipment. The second sub-aim focuses on optimization of process parameters in the operating process, to reduce energy consumption. Whereas in the first sub-aim, adoption of new-generation or rebuilt machines with advanced energy-saving devices is very expensive, a much lower cost is required in the optimization-based second aim which only requires experimental or simulated data. In this sub-aim, a mathematical model among process parameters and an energy model are established, based on supplied data.

Energy-saving via process parameter optimization has attracted much research attention. By using analytical method or artificial neural network (ANN), the interrelationship between process parameters and energy consumption was established [4, 5]. However, among these studies, product quality was lacking.

To reduce energy-consumption and carbon emissions, while increasing product quality in the injection molding process of plastic car fender, this paper proposes a multi-objective optimization framework that addresses multiple considerations in the process. The paper focuses on optimiz-

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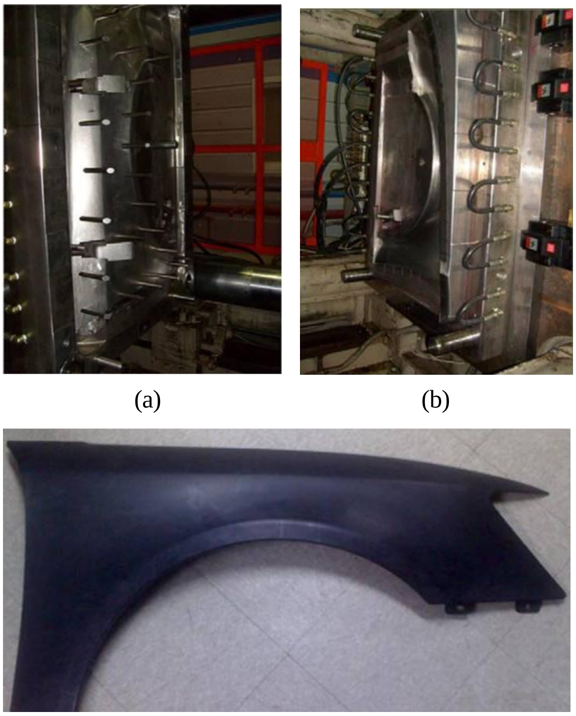

(a) (b)

(c)

Figure 1. The prototyping mold and plastic car fender: (a) movable die, (b) stationary die, (c) molded part.

ing process parameters which can be changed during the molding process. The remainder of the paper is organized as follows. Section 2 introduces a framework to approach and solve multi-objective optimization problem. Section 3 presents numerical experiments and descriptive data analysis. Section 4 describes optimization results. Section 5 gives conclusions and goes over possible future work.

2. Optimization framework

2.1 Optimization problem

The prototyping mold and plastic car-fender product are shown in Figure 1. The part's dimension were 650 mm × 1160 mm × 235 mm, and the thickness was fixed at 2.8 mm. In the injection molding process of car fender, energy is consumed by plasticization, heating, molten-plastic injection, clamping forces, auxiliary device-operation, and mold movements / part-ejection. Through previous studies [6], manufacturing data and the interviews with company experts, an investigation indicated that the greatest amount of energy was consumed in plasticization, where the energy-consumption rate was 48%. Barrel heating expenditure was 19%. Clamp-force use rate was 12%. Injection force consumption-rate was 11%. Only small amounts of energy (4% per each process) were used by linear movements to open and close molds, and retract barrels for cooling. The share total energy consumption is shown in Figure 2.

According to the analysis of energy consumption, except

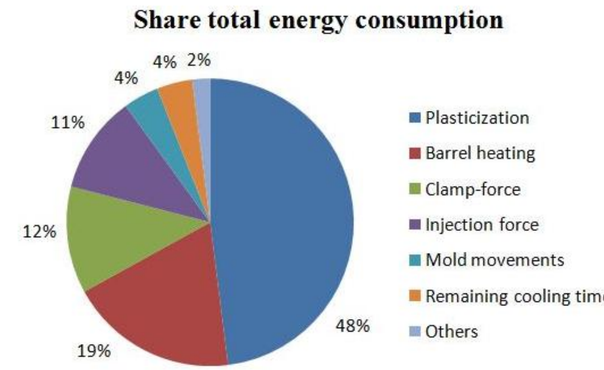

Figure 2. Share total energy consumption.

the plasticization and heating process, clamping force can be considered as the great influence factor for energy saving. In this paper, we focus on the minimizing clamping force which gives rise to clamping energy based on the optimization of process parameters. Additionally, due to thin-shell characteristic, the warpage values that should be minimized to improve molded product quality are employed as the optimization criteria. To save the time and costs, the simulation-based optimization is employed instead of expensive physical experiments. Because the simulation values correlated sufficiently with the experimental values [7], a FE-based model is developed to obtain desired criteria. The commercial software, namely Autodesk Molflow Insight 2012 that can guarantee reliable results is used to simulate the molding process.

During the simulation, the maximum value of injection pressure has been set as the fixed value according to real manufacturing conditions. Based on the molding process conditions and previous studies [2-5], five critical parameters are considered as control factors: mold temperature (T_M), melt temperature (T_{ME}), packing time (P_t), packing pressure (P_P), and cooling time (t_c). Multiple-objective optimization functions can be described in the below equation:

$$\begin{cases} Minimizing\ F(T_M,\ T_{ME},\ P_t,\ P_P,\ t_c) \\ Minimizing\ W(T_M,\ T_{ME},\ P_t,\ P_P,\ t_c) \end{cases}$$

$$\begin{cases} T_{M\min} \le T_M \le T_{M\max} \\ T_{ME\min} \le T_{ME} \le T_{ME\max} \\ P_{t\min} \le P_t \le P_{t\max} \\ P_{P\min} \le P_P \le P_{P\max} \\ t_{c\min} \le t_c \le t_{c\max} \end{cases} \qquad (1)$$

where F denotes the clamping force, W presents the warpage.

2.2 Optimization strategy

In this section, a multi-objective optimization framework is presented to obtain optimal process parameters. Figure 3 describes two stages of the multi-objective optimization procedure of the proposed approach. A systematic methodology based on response surface methodology (RSM) is adopted to establish a relationship between process parameters and the performance of objective functions. The RSM relates to re-