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Optimal design of heating system in rapid thermal cycling blow mold by a two-step method based on sequential quadratic programming

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ABSTRACT

The blow molded parts made of engineering resins usually possess poor surface quality, and thus cannot satisfy the requirement of high-gloss appearance in some applications. For this reason, a rapid thermal cycling extrusion blow molding (RTCEBM) technology was developed, the process principle was presented and its process procedure optimization was also analyzed. Aiming at obtaining uniform temperature distribution on both mold cavity and core surfaces, a two-step optimization method based on sequential quadratic programming (SQP) algorithm was proposed for designing the heating system in RTCEBM mold, and its effectiveness was demonstrated by optimizing the electric-heating system for the RTCEBM mold of an automotive spoiler. After optimization, the maximum core surface temperature difference is reduced by 77% from the initial value of 22.06 °C to the optimal value of 5.05 °C; meanwhile, the molding process coordination can also be ensured. This work may provide an effective method to optimize the heating system for these molds with cavity and core sides to be heated simultaneously.

1. Introduction

Extrusion blow molding (EBM) is a major plastic processing technology, with products ranged from packaging containers to complex industrial parts [1]. Due to its advantages of lower production cost, double-wall hollow part construction and high part strength-to-weight ratio, more and more industrial plastics parts, especially for those used in automobile, are gradually turning to be produced by EBM technology in recent years. In the traditional EBM, the mold temperature is usually maintained at a lower level to rapidly cool the part for high production efficiency. As a consequence, the skin layer of parison will be solidified instantaneously as soon as it contacts the cold mold wall, resulting in that the surface quality of blow molded parts is relatively poor, especially for those molded with engineering plastics (e.g., ABS, PA, etc.). For some exterior parts requiring high-gloss appearance, the defects with surface quality (particularly roughness, sunken points and orange peel) must be eliminated via sanding, polishing and painting. These secondary operations not only dramatically increase the cost and decrease the production efficiency, but also are harmful to the surrounding environment and operator's healthy.

Rapid thermal cycling molding, as an advanced plastics molding technology based on rapid mold heating and cooling [2], has been developed and widely applied in the field of injection molding for producing high-gloss parts (such as LCD panel) in the past few years. Inspired by this, the authors also tried to systematically integrate the rapid thermal cycling molding process with the EBM (referred as rapid thermal cycling extrusion blow molding) with the expectation to directly obtain high-gloss blow molded parts and thus to eliminate the post-processing operations. Fortunately, the preliminary experiments for molding an automotive plastic part (i.e., automotive spoiler) were quite successful, the molded automotive spoilers exhibit high-gloss surface appearance (as shown in Fig.1) that can be directly used for the final assemble process, and meanwhile the molding cycle time is comparative to that of traditional EBM process [3]. However, there still have many issues (some of which will be discussed in this work) to be addressed for promoting the large-scale industrial application of this developed technology.

For rapid thermal cycling molding, rapidly and uniformly heating the mold cavity surface is the key to realize its successful application. Many rapid mold heating methods (e.g., induction heating [4–6], convection heating [7], resistance heating [3, 8, 9] and infrared heating [10], etc.) and novel mold structures [9, 11, 12] were proposed to obtain high mold heating efficiency. More detailed descriptions on these mold heating methods and mold structures can be found in the insightful review article given by Yao [2]. As to uniformly heating mold cavity surface, many efforts were done from the aspect of simulation-

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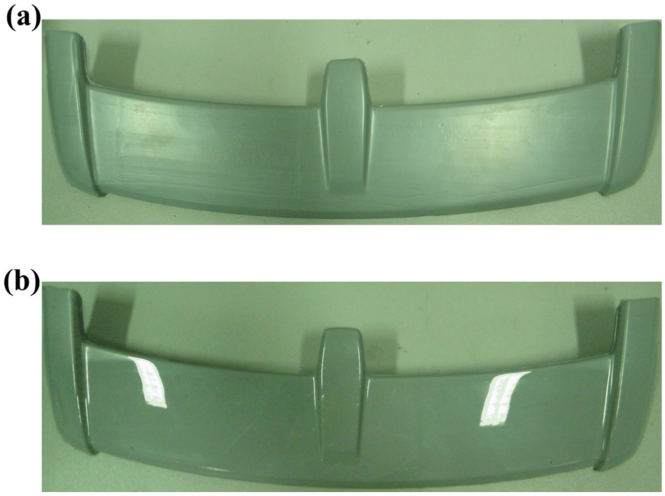

Fig. 1. Comparison of automotive spoilers molded by (a) traditional EBM and (b) rapid thermal cycling EBM.

based mold heating system optimization in the past few years. Optimization based on surrogate model (e.g., response surface model [13–15], artificial neural network [15], Kriging model, etc.) and direct numerical optimization [3, 16] were the two typical categories adopted, depending on the mold structure, number of design variables and so forth. In these previous studies, however, it was usually that only the heating system located in cavity mold-half was optimized. This is mainly because most exterior parts (especially for the injection molded parts, e.g., LCD panel) only have the strict requirement of high-gloss appearance on their front surface, their back surface will be invisible after assembly. If both the front and back surfaces of a part had high-gloss appearance requirement, the heating systems located in both cavity and core mold-halves should be optimized simultaneously. While this may be more difficult by considering the following two issues: (i) the time used for respectively heating the mold cavity and core sides should be kept at the same for the coordination of molding procedures; (ii) the layout of heating system arranged in the core mold-half is much more restricted than that in cavity mold-half, because the potential geometrical interference among mold heating system, part ejector pin, mold venting/vacuum system, mold temperature detector and mold cooling channels must be completely avoided.

In the present work, we mainly focused on some industrial blow molded parts having strict requirement of high-gloss appearance for their both front and back surfaces. A two-step simulation-based optimization strategy was proposed to simultaneously optimize the heating systems located in both cavity and core mold-halves based on sequential quadratic programming (SQP). Finally, effectiveness of the proposed strategy was demonstrated by optimizing the electric-heating systems for a blow mold of automotive spoiler.

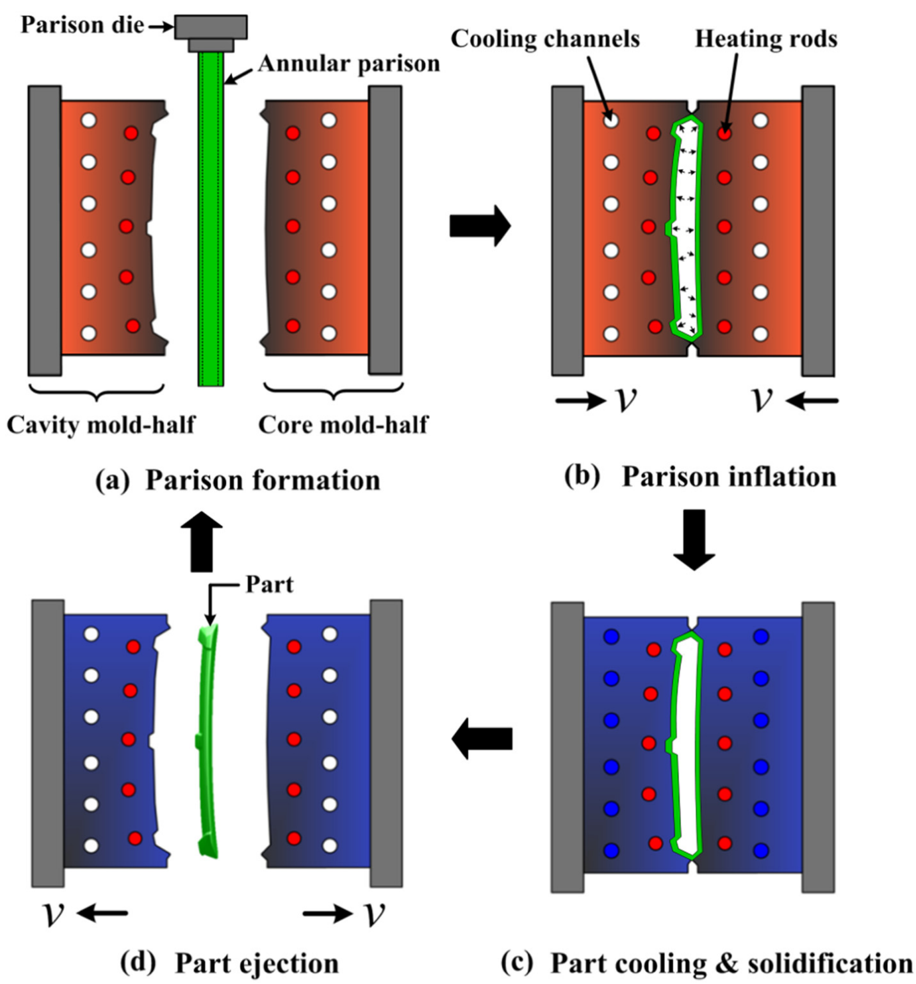

Fig. 2. Schematic of process principle for RTCEBM.