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Development of a rapid thermal cycling molding with electric heating and water impingement cooling for injection molding applications

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HIGHLIGHTS

- A RTCM technology is developed for injection molding applications.
- High mold heating/cooling efficiency is achieved using the developed RTCM technology.
- A new cavity insert-fixing mode is proposed to alleviate RTCM mold thermal stress.
- The developed RTCM process can dramatically improve surface quality of molded parts.
- The feasibility of developed RTCM technology for injection molding applications is demonstrated.

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ABSTRACT

A rapid thermal cycling molding (RTCM) technology with electric heating and water impingement cooling is developed. To illustrate the feasibility of this technology in injection molding, a RTCM mold for cover plate is constructed. Experimental measurements and numerical simulations are conducted to evaluate the mold thermal response. The results show that the desired characteristics of high mold heating and cooling efficiencies are achieved. A new cavity insert-fixing mode is proposed to alleviate the thermal stress in cavity insert. It is found that the maximum thermal stress can be reduced by 75% for the constructed RTCM mold with the new mode, which is expected to result in greatly improved mold fatigue life. The surface quality of both polycarbonate (PC) and 20% glass fiber-reinforced PC (GF-PC) cover plates molded using the developed RTCM technology is dramatically improved and the surface defects that usually occur in conventional injection molding (CIM) process are eliminated. Meanwhile, the molding cycle time is not significantly increased for the RTCM process in comparison to the CIM process. So the feasibility of the RTCM technology developed for injection molding applications is successfully demonstrated.

1. Introduction

The industrial plastics parts are becoming thinner, lighter, and also possess high surface quality and accuracy with the rapid development of 3C (Computer, Communication and Consumer electronic) industrials and increasingly strict requirement on energy saving and emission reduction. It is more and more difficult for the conventional injection molding (CIM) technology to satisfy the requirements in modern industry. For this reason, a new injection molding technology named rapid thermal cycling molding (RTCM) technology was developed and has been attracted much attention in the past few years. The main difference between the CIM and RTCM processes is the mold temperature control manner. A constant mold temperature control strategy is usually adopted in the former, whereas a dynamic mold temperature control approach by alternatively heating and cooling the mold in each molding cycle is applied in the latter. In RTCM process, usually the mold is rapidly heated up to about 10 °C higher than the thermal deflection temperature of polymer used before melt filling, and subsequently the mold is cooled down quickly when the filling or packing stage is completed for part ejection. Owing to higher mold temperatures in the filling and packing stages, the frozen layer that is inevitable in CIM can be completely eliminated in RTCM, resulting in that the melt flow resistance is reduced, the required injection pressure and clamping force of molding machine are decreased and more

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uniform cavity filling pressure distribution can also be obtained. Meanwhile, rapid cooling can maintain the molding cycle time at an acceptable level. Many researches in literature demonstrate that the RTCM process can effectively lengthen the melt flow path [1,2], enhance the replication of microstructures [3–6], improve the part surface appearance [7–10] and reduce the flow-induced molecular orientation [11,12] without significant increase in molding cycle time. Therefore, RTCM process is of great technical importance.

For mass production of parts using RTCM process, rapid mold heating and cooling are necessary to shorten the cycle time and thus increase the productivity. Many efforts made in recent years mainly focused on developing rapid mold heating/cooling methods and designing novel mold structures to achieve the purpose. The proposed rapid mold heating methods mainly include resistance heating [8,9,13], induction heating [4,5,7,14], high-frequency proximity heating [12,15], infrared heating [2,16], gas-assisted heating [17] and convection heating using hot fluids such as oil [18], water [19] and steam [20,21]. More mold heating methods and their principles, advantages and drawbacks can be found in the review article given by Yao et al. [22]. Additionally, some investigations have been done to optimize the heating systems in RTCM molds for achieving rapid and uniform mold heating [9,19,23–25]. As the rapid mold cooling methods, the regular cooling manner by circulating water in mold cooling channels can be utilized in RTCM. To enhance the cooling efficiency, the optimized layout of cooling lines and the coolants with low temperatures and large flow rates are more preferred. Moreover, the conformal cooling channel has been demonstrated more efficient to rapidly and uniformly cool the mold [26]. From the view of mold structure design, how to reduce the amount of mold material to be thermally cycled as well as ensure the adequate strength and rigidity of RTCM mold are the key issues. Based on these objectives, some novel RTCM mold structures including multilayer mold [13,27–29], scaffold mold [12,30,31] and the mold with floating cavity/core [32] have been proposed and developed.

Comparing with CIM mold, the working conditions of RTCM mold are relatively worse due to the alternative thermal stress resulted from cyclic mold heating and cooling in each molding cycle. Therefore, the fatigue cracks are easily induced in the RTCM mold and thus its lifetime is usually much lower than that of CIM mold. When the micro-crack appears on mold cavity surface, the mold needs to be repaired by welding, heat treatment and polishing, resulting in great increase in cost and production delay. For this reason, it is important to design the RTCM mold with reasonable structure to alleviate the mold thermal stress and thus to enhance its durability. Up till now, there exists only a little of work referring to the thermal stress analysis of RTCM mold. Zhao and coworkers [33,34] systematically analyzed the thermal stress, deformation and fatigue lifetime for a large LCD TV frame mold using finite element method (FEM). The results showed that the FEM can be used as a useful tool to properly predict the mold fatigue life and positions of induced micro-cracks. Moreover, some strategies related to mold material, mold structure design and so on were proposed to improve the lifetime of RTCM mold.

In the present work, a RTCM technology with electric heating and water impingement cooling is developed to achieve high mold heating and cooling efficiencies. A corresponding RTCM mold is also designed and constructed. Experiments and FEM analyses are conducted to evaluate the thermal response of the mold. Thermal stress analysis is also performed to evaluate the thermal stress distribution in cavity insert, and then a new cavity insert-fixing mode is proposed to alleviate the thermal stress. Finally, the surface quality of the cover plates molded with the RTCM and CIM processes are compared to illustrate the feasibility of developed RTCM technology in injection molding.

2. Mold structure and working principle of RTCM technology with electric heating and water impingement cooling

Fig. 1 illustrates the typical mold structure for the developed RTCM technology with electric heating and water impingement cooling. In the rapid mold heating stage of RTCM process, the mold is in the open state as shown in Fig. 1a, the heating rods installed in the cavity and core plates are used to rapidly heat the mold. Because the water impingement cooling modules including the cooling channels and jet nozzles are individually designed in the corresponding cooling plates, the thickness of the cavity and core plates can be designed to be much thinner and thus their masses are greatly decreased. Further, the air gap between the cavity or core plates and the corresponding cooling plate as well as the insulating sheets set between the supporting pillars and cavity/core plates are good insulated layers, which can effectively avoid the heat to be transferred from the cavity and core plates to the corresponding cooling plates, thus the heat loss is greatly decreased. Therefore, the cavity and core plates can be rapidly heated with low heat consumption. When the temperatures of the cavity and core plates are elevated to the preset one, the heating rods are turned off to stop heating, and then the mold is closed for melt filling as shown in Fig. 1b. In the melt filling stage, the supporting pillars designed between the cavity/core plates and corresponding cooling plate can effectively increase the strength and rigidity of cavity/core plates and hence decrease their deformation under high melt injection pressure and clamping force. The mold cooling stage starts as soon as the melt filling or packing stage is completed. In the mold

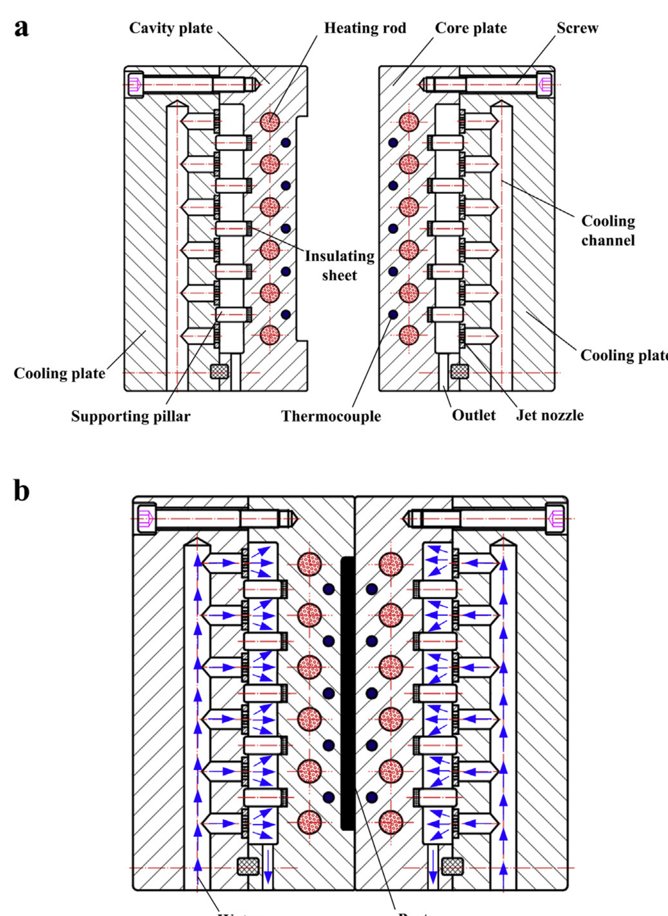

Fig. 1. Typical mold structure of proposed RTCM technology with electric heating and water impingement cooling. a: Mold in opening state; b: mold in closing state.