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Influence of using pulsed cooling for mold temperature control on microgroove duplication accuracy and warpage of the Blu-ray Disc ☆

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Abstract

The usage of pulsed cooling for mold temperature to improve the molding process has been gaining increasing attention. In this study, Blu-ray Disc substrates, adapted for the commercial format media, were injection molded by combining pulsed-cooling technology. When applying pulsed cooling, coolant circulation is usually stopped during the melt-filling process and the mold opening and closing period. This leads to the additional cavity surface temperature increase and may vary part qualities. The correlations of mold temperature, cycle time, and pulse cooling duration with microgroove duplication accuracy and substrate qualities such as warpage in different directions were investigated in details. Measured results were also compared with those of injection-compression molded Blu-ray Disc using conventional cooling. The experiments showed that by using pulsed cooling in a proper manner one may manufacture Blu-ray Discs with lower warpage, higher accuracy in microgroove replication meanwhile reducing coolant temperature by 8 °C and shortening the cycle time by10% as compared to the conventional-cooling process. The usefulness of pulsed cooling and its potential in improving part quality and reducing cycle time during injection molding have been successfully demonstrated.

Keywords: Pulsed cooling; Blu-ray Disc; Microgroove duplication accuracy; Warpage

1. Introduction

Reduced cycle time and lower energy usage remains an important issue for the successful application of the injection molding process from the view point of commercial benefit, as a result, control of the mold temperature is a very important task. Although low mold surface temperature will reduce the cooling time, however, it may also result in poor molded part qualities. A variable mold temperature control, i.e., maintaining high mold temperature during the melt-filling process and lowering the mold temperature to below deflection temperature during the post-filling process has been paid attention increasingly. From the part manufacturer's viewpoint, it is very important to understand the dependence of part qualities and cycle time on the design of the heating/cooling elements, as well as the control of the cooling/heating medium. The newly developed mold temperature controls [1–3] require assisted heating source such as electrical heating, infrared heating and

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induction heating, etc., for the mold and thus results in either extra operation and/or operation complexity. Two cooling systems, namely, conventional cooling and pulsed cooling, can be used for the mold temperature control with easy operation and without additional mold cooling design change. The conventional-cooling method also named as continuous cooling or direct cooling uses a steady, continuous flow of coolant at the required set temperature. The initial temperature is adjusted such that the mold surface always maintains at the set temperature at the start of the molding cycle. Pulsed-cooling technology is one of the recently developed innovative techniques in mold temperature control. The system can maintain temperature during injection phase by closing manifold valves and stopping coolant flow. When the injection phase ends, the valves are reopened for continuous flow until the mold is cooled down to the desired temperature. Because of the coolant stagnation and the associated poor heat transfer, the mold temperature may be subjected to additional rise by 10 to 15 °C (as compared to that of conventional cooling) depending the total cycle time, the mold size and the cooling channel design. It appears to be a very efficient and economical method for molding optical media which requires high mold temperature to improve dimension accuracy and reduce birefringence. Particularly, the additional mold temperature rise occurs only around the melt-filling phase and would not affect the cycle time and the molding cost. A schematic comparison of mold temperature variations for conventional cooling and pulsed cooled molding [4] is made in Fig. 1.

Blu-ray Disc is a new high definition platform with microgroove/pit geometry. In the injection molding process, the quality of these substrates such as microgroove depth duplication accuracy, birefringence, diffraction efficiency and warpage in tangential, radial and vertical directions are very important, and are significantly influenced by the processing method, molding conditions, and the mold tool design. Particularly, the design of the cooling system substantially determines the cooling time and the quality of injection-molded parts. At present conventional-cooling method is still the most popular way to produce plastic parts. Recently, few studies concerning about molding parts via pulsed-cooling method have been reported [5–9]. Systematic studies of the processing characteristics and its influence on part qualities are still insufficient. The relevant research results are more or less the type of technical reports. These studies basically reveal that pulsed cooling may have the advantage and potential as compared to the conventional cooling. Research on various optical disc products indicated that there could be a reduction in cooling time of up to 30% and further investigation showed other technical and costs advantages [5,6]. Detailed finite element simulation [7] of the molding process indicates that pulsed cooling is able to achieve better control and stability of the temperature compared to the conventional cooling. On the other hand, various experiments [8] with the used of pulsed cooling shows several improvement for DVD type format discs like improved birefringence, better control of substrates dishing, also improvement of the forming the pit structure, resulting in enhanced measured discs electrical signals. A more recent study by Mischke et al. [9], who evaluated cycle time, microgroove depth/pit replication quality and physical properties of the BD substrates manufactured by pulsed-cooling molding process, found that by using a pulsed-cooling system one may manufacture BD ROM and BD-RE type of discs with much shorter cycle time than with the conventional-cooling process and at reduced mold temperature. As far as part quality is concerned, the pulsed cooled molding produces substrates with lower birefringence, tilt, dishing, very good groove/pit replication quality.

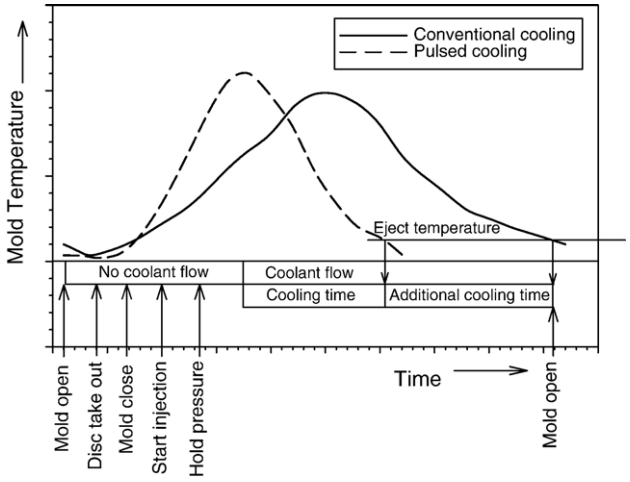

Fig. 1. A schematic in comparison of mold temperature variations for conventional cooled and pulsed cooled molding process.