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Warpage control of headlight lampshades fabricated using external gas-assisted injection molding

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ABSTRACT

Headlight lampshades with an uneven part thickness and large-area complicated geometry often exhibit uneven shrinkage and considerable deformation when fabricated using injection molding. Conventional strategies for controlling shrinkage and warpage involve optimizing the gate number and location, cooling system, and mold conditions and performing annealing in a secondary process; however, conventional strategies are limited in improving the quality of injection molding. This study involved employing conventional approaches and external gas-assisted injection molding (eGAIM) to control part shrinkage and warpage effectively. The research consisted of three stages: (1) using computer simulations to optimize the mold design and molding conditions and, thus, reduce the shrinkage and warpage of headlight lampshades; (2) verifying the performance experimentally using a miniaturized geometry of the one use in (1); (3) applying eGAIM to show the potential of further improving part warpage. Simulation and experimental results indicated that optimizing the gate location facilitates improving the flow balance and reducing the filling pressure, leading to a reduction in part deformation. An optimal layout of cooling channels combined with two-stage holding conditions contributed to a superior cooling effect and low volumetric shrinkage. Parts fabricated using eGAIM exhibited less volumetric shrinkage than did parts fabricated using conventional injection molding. Moreover, annealing treatment can further reduce the deformation of molded parts. This case study investigated headlight lampshade deformation and was systematically conducted; the experimental results showed the feasibility of using eGAIM to minimize part warpage.

1. Introduction

Products fabricated through injection molding can be classified into interior and exterior parts. Interior parts require rigid dimensional control, whereas exterior parts require high appearance quality. Cosmetic headlight lampshades used in automobiles require both high appearance quality and accurate dimensions; however, defects occurring in injection molding, such as substantial shrinkage and warpage, often cause clearance or interference problems in assembly. Consequently, precise volumetric shrinkage and warpage in injection-molded parts is crucial to product- and mold-design engineers. Numerous factors can affect the shrinkage rate of processed resins, including melt temperature, cooling rate, part thickness, and holding pressure and time [1]. These factors are crucial in introducing part shrinkage and internal residual stresses that result in low dimensional accuracy and appearance quality. For instance, increased packing pressure facilitates reducing shrinkage, but frequently results in high internal stress. The formation of nonuniform packing pressure, accompanied by uneven planar shrinkage, contributes to part warpage.

The main cause of warpage in injection-molded parts is their uneven volumetric shrinkage at high and low temperatures, which can be induced by thermal, pressure, and flowing orientation effects [2]. Temperature determines the change in volumetric shrinkage on processed resins. The specific volume of injection-molded parts cooled from a high temperature under constant pressure changes considerably, causing a high shrinkage rate. Differential cooling results in variations in sectional shrinkage [3]. The temperature difference between upper and lower surfaces causes differential shrinkage between the cavity and the core and a bending moment after a part is ejected from the mold; this causes either warpage or residual stress, depending on the mechanical stiffness of the part [4,5]. In addition, the layout of cooling channels on the core and cavity affect the uniformity of the cooling rate. A

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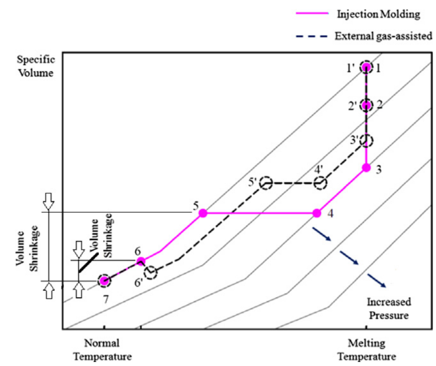
deviation in the cooling rate causes uneven shrinkage, especial for thick parts, which often exhibit high shrinkage. Moreover, the thermal effect contributes to generating internal stress in injection-molded parts during the cooling stage by first solidifying the outer layer along the thickness direction and then limiting the shrinkage direction of the inner part that is subsequently cooled.

Injection-molded parts cooled under high pressure exhibit only slight shrinkage. The level of pressure is associated with the location of molten resin in the cavities [6,7]. For example, near-gate resin is under high pressure and therefore exhibits minor shrinkage. By contrast, resin far from the gate is treated with low pressure and exhibits substantial shrinkage. Packing profiles can be used to establish an approximately uniform distribution of volumetric shrinkage in a molded product. A constant packing pressure results in maximal volumetric shrinkage at the end of flow and minimal volumetric shrinkage near the gate region. A decayed pressure profile enables establishing an approximately uniform volumetric shrinkage by causing the regions of resin cooling near the gate to freeze at effectively the same pressure in regions further from the gate.

Shrinkage is also affected by the direction of material orientation. During shear flow, polymer molecules become aligned with the direction of flow. The extent of this orientation depends on the shear rate that is applied to the material. When the material stops flowing, the induced molecular orientation begins to relax at a rate depending on the relaxation time of the material. When the melt temperature is increased, unoriented molecules are fixed in a frozen layer and the material remains hotter for a longer period of time, allowing relaxation to occur and thereby reducing the orientation effect. Increasing the injection speed causes shear heating in the mold to increase; consequently, the material is more highly oriented because of the speed of injection, and the additional shear heating reduces the viscosity of the material, causing it to remain hotter for a longer period of time and allowing relaxation to occur; thus, the orientation is reduced.

Gas-assisted injection molding (GAIM) operating at a pressure lower than that of conventional injection molding (CIM) exhibits numerous advantages, including elimination of sink marks and warpage, reductions in part weight and shrinkage, and decreased cycle times [8]. In a typical GAIM process, a gas is injected through a gas needle into the interior of a part or into gas channels designed as part of a product; this is called internal gas-assisted injection molding (iGAIM). However, iGAIM is restrictive in producing transparent exterior parts such as headlight lampshades, which are composed of polycarbonate (PC) or Polymethylmethacrylate (PMMA). External gas-assisted injection molding (eGAIM) differs from the iGAIM process in that the gas is not directly injected into the interior of the product. When the mold is completely filled with molten resin, the gas is injected between the mold wall (core side) and the molten resin (Figs. 1 and 2); subsequently, the gas

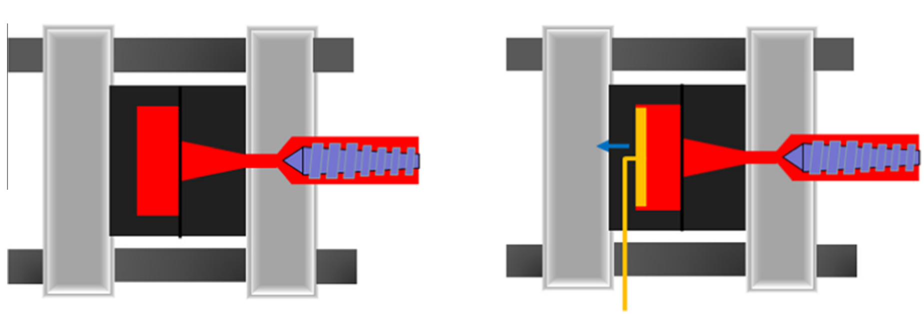


Point	CIM	Point	eGAIM
1	Start of injection	1’	Start of injection
2	Start of holding	2’	Start of holding
3	Peak pressure	3’	Peak pressure
4	Gate frozen & End of holding	4’	Gate frozen & Start of gas packing
5	Polymer departed from mold surface	5’	Cavity pressure drop to external gas pressure
6	Mold open	6’-6	Gas release & Mold open
7	Cooling to normal temp.	7	Cooling to normal temp.

Fig. 2. P-V-T diagrams of CIM and eGAIM.

pressure presses the molten resin toward the opposite mold wall and acts as both the packing and holding pressures. The eGAIM process may offer some of the same benefits (Table 1) as iGAIM does, and its influence on packing and packing-related problems are believed to be considerable, particularly for shrinkage, sink marks, and warpage reduction [9–11]. In the CIM process, the packing pressure is gradually reduced as the distance from the gate increases because of melt solidification. However, in the eGAIM process, the gas directly presses on the part and is not affected by the filling distance, leading to shrinkage reduction. The required pressure for eGAIM is lower than the conventional packing pressure, preventing mold deformation and high internal stress in the part [12,13].

Although GAIM has been used extensively in the past decade, research has focused mainly on iGAIM, exploring the types of gas channel and the effect of injection molding conditions on part quality and other aspects. Compared with iGAIM, eGAIM has been used less widely. The few research papers on eGAIM have primarily focused on improving the surface quality of parts [14]. Chen et al. [15] investigated the gas packing characteristics of eGAIM and its effect on part shrinkage in comparison with that of CIM. The results indicated that gas packing provides uniform gas pressure distribution along the cavity and achieves equal shrinkage values



(a) (b)

Fig. 1. Schematic diagram of eGAIM: (a) melt filling; (b) gas packing.