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Effects of insert film on asymmetric mold temperature and associated part warpage during in-mold decoration injection molding of PP parts ☆

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ABSTRACT

In mold decoration (IMD) injection molding is a relatively new multi-process technique that has been used for improving the surface quality and achieving colorful cosmetic surface of molded parts. During IMD processing, the film having the same shape as mold cavity is first inserted into the mold then molten polymer is injected into the cavity. Heat transfer in the cavity surface is significantly retarded because of the low thermal conductivity of film. As a result of the asymmetric melt and mold temperature, thermal-induced part warpage easily occurs. The effects of inserted film on the asymmetric mold temperature field of IMD injection molding process for polypropylene (PP) parts were investigated. Experiments were conducted under various conditions of mold temperature, melt temperature and film thickness. The associated part warpage and crystallinity due to the asymmetric mold temperature were examined. It was found that the heat transfer retardation results in a delay in mold temperature drop at film–mold interface of the cavity surface and the maximum temperature difference compared with that of conventional injection molding without film may be as high as 10 °C. The retardation-induced mold temperature difference and part warpage increased with increasing melt temperature and film thickness, whereas they decreased with increasing mold temperature. The crystallinity of molded PP parts increased through insertion of film. The mold temperature field of the IMD process and molded part's warpage were predicted via numerical analyses. The predicted values showed reasonable agreement with the experimental results. Asymmetric cooling system design reduced part warpage when IMD processing was used.

1. Introduction

Injection molding [1] is one of the most widely used and complex polymer processing techniques as products with complex geometry can be manufactured rapidly at relatively low cost. In-mold decoration injection molding (IMD), also named as film insert injection molding, is a relatively new and cost effective injection molding technique in which molten resin is injected into the cavity after a decorated film is preformed as the shape of the mold cavity and placed into one side of the mold walls, usually in the cavity surface. The primary advantage is the integration of several manufacturing steps (production and decoration of the molding) into one production operation [2]. This technique can reduce the number of production stages and component parts, cutting both production time and cost while offering the potential to improve the quality, complexity, and durability of the finished products. High surface quality of film injection molded parts is obtained without any post-processing operations, such as screen printing or spray painting; therefore, IMD is a highly advanced method compared with the conventional injection molding [1–4]. Moreover, the injected hot melt resin may partially join to the film, resulting in enhancement of adhesion between the film and the molded part after cooling [5,6]. Recently, IMD has been used for production of various molded products with improved surface quality, such as automotive panels, cellular phone cases, and logo imprinted plastic products.

Although there are some advantages for IMD processing, the challenge of IMD process is to overcome the film positioning, ink wash-out, and product's warpage issues. During a mold filling stage, there are quality risks of flashing away the film from the right position and washing away the pre-print ink from the film surface. In addition, during the cooling stage, there is a warpage problem due to imbalanced heat dissipation on both sides of product. Heat transfer within the IMD part in the perpendicular direction to the cavity wall can be retarded similar to that of cavity surface coating [7] because the film is attached to the cavity wall. Furthermore, the heat transfer along the flow path causes different temperature boundaries for cavity surface (with film) and core surface (without film). The non-uniform heat transfer in the cavity introduces non-uniform temperature distribution across the gapwise direction during filling and cooling stages (Fig. 1). As a result

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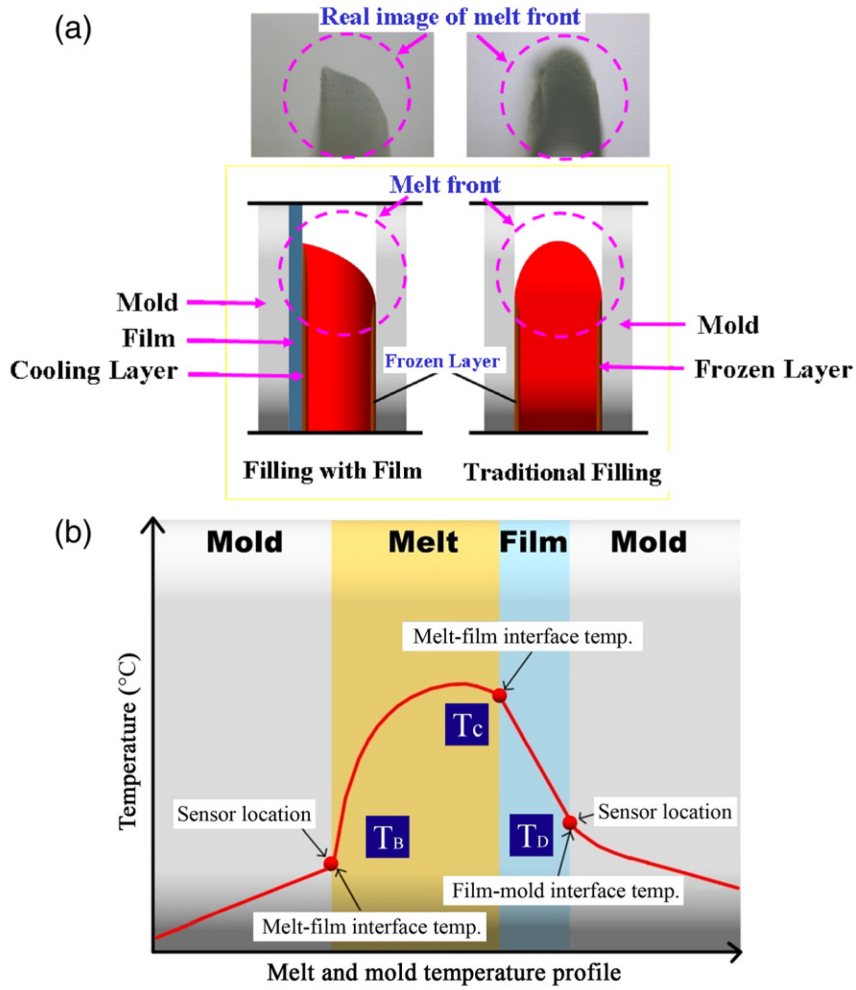

Fig. 1. Schematic of (a) film-induced asymmetric flow front advancement, and (b) asymmetric melt and temperature profile.

of asymmetric temperature distribution in the cavity wall unbalanced flow front advancement, severe warpage and stress, and other effects on the part's properties – such as non-uniform crystallization and orientation – may occur [3–9]. All these studies were mainly focused on the processing characteristics. Although thermal effect from inserted film has been reported [3,4,10–12], there is no comprehensive study in the literature on the effects of molding conditions, including melt temperature, mold temperature, and film material and thickness, on the simultaneous film retardation induced temperature drop and part warpage. Meanwhile, detailed investigations on the characteristics of mold temperature field and warpage via simulations or measurements are not yet reported. It is essential to understand the heat transfer behavior at the interfaces of mold–polymer and melt–film–mold induced from the inserted film. This understanding can lead to attain the best quality of IMR products.

In this study, the asymmetric mold temperature profiles in the direction perpendicular to the cavity wall due to the one-side film attachment was the key concern for IMD processing. To investigate effects of the inserted film on the mold temperature field and warpage of IMD injection molding, polypropylene (PP) was injection molded under various conditions of mold temperature, melt temperature, film material, and film thickness. Temperatures of mold–polymer (side without film), polymer–film, and film–mold (film side) interfaces were measured. To understand the variations of temperature at the polymer–film interface during processing, thermal simulation and analysis of the IMD process were also performed. The associated part warpage and crystallinity changes caused by the asymmetric mold temperature were inspected as well. Furthermore, the experimental results were also compared with the numerical analysis results.

2. Experimental work

2.1. Materials

The polymer material used in injection molding experiments was PP (Globalene 7533, Taiwan LCY Chemical Corporation) with density of 897 kg/m^3, thermal conductivity of 0.255 W/mK, and specific heat of 3100 J/kgK. The mold was made by P20 steel with density of 7850 kg/m^3, thermal conductivity of 31.5 W/mK, and specific heat of 501.6 J/kgK.

The PC films with thicknesses of 0.125 and 0.175 mm and PET films with thicknesses of 0.036 and 0.05 mm were used and attached to one side of the mold walls. The associated effects on mold temperature, warpage and relevant influences were investigated. The PET film had density of 1405 kg/m^3, thermal conductivity of 0.2745 W/mK, and specific heat of 1924 J/kgK, whereas PC film had density of 1250 kg/m^3, thermal conductivity of 0.207 W/mK, and specific heat of 1224 J/kgK.

2.2. Film insert injection molding

Four square plates, with dimensions of 98.5 × 98.5 × 1.2 mm, were molded using an injection molding machine (Sodick HSP100EH2 Japan). The mold had a fan-shaped gate of 20 mm length and entrance dimensions of 27 × 1 mm with 5.5 mm of beginning and 7 mm of ending