International Communications in Heat and Mass Transfer 38 (2011) 1330–1334

Contents lists available at SciVerse ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Investigation of cooling effect at corners in injection molding ☆

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ARTICLE INFO

Available online 26 October 2011

Keywords:
Simulation
Injection molding
Corner effect
Cooling
Simulation

ABSTRACT

Many parameters influence the warpage developing at the corners of injection molded plastic parts. One of the main causes of this deformation is the asymmetrical cooling of the injection mold. This study presents an injection molding analysis of the heat flow developing in injection molds. The analysis shows that significant temperature difference appeared between the two sides of the mold after the hot polymer melt had filled the cavity. It was highlighted that the unevenness of the cooling should be considered during the mold design in order to avoid the warpage of the parts.

1. Introduction

The injection molding process is a high speed, automated process used to produce plastic parts with complex geometries and fairly tight dimensional tolerance requirements. The quality of the product is determined by the process parameters and several defects can occur because of improper mold design or incorrect machine setup [1,2]. One of the main errors is shrinkage which derives from the decreasing volume of the injection molded part during the cooling phase of the process. Shrinkage causes warpage as it appears unequally throughout the geometry. The warpage is strongly influenced by non-uniform cooling, differential shrinkage and orientation effect [3–5]. Differential shrinkage is caused by variation in crystalline content and volumetric shrinkage. Orientation effect is the result of the ratio between the in-flow shrinkage and the cross-flow shrinkage. Unfilled polymers shrink more in the flow direction (in-flow shrinkage) compared to the direction perpendicular to flow (cross-flow shrinkage); on the other hand reinforced plastics shrink more in the cross-flow direction than in the direction of flow. This difference in shrinkage causes the orientation effect. Non-uniform cooling can cause significant differences in shrinkage through the thickness of the part as it cools from process temperature to room temperature. Non-uniform cooling creates a more significant problem in areas such as corners, where there are differences in the sizes of the core and cavity mold volumes required to be cooled down. The cooling becomes asymmetric as the core side can be difficult to cool effectively compared to the cavity side of the mold. Hotter surfaces of the plastic part shrink more than cooler surfaces and therefore, due to stresses introduced during this cooling phase, the corner angle of the part becomes smaller than the nominal mold one after ejection from the mold. This phenomenon is known to be the main cause of corner warpage in injection molding of thermoplastics [5,6].

The use of injection molding simulation provides a method to analyze this effect. Not only part models, but also injection mold designs, can be examined and optimized with simulation [2,7,8]. Because of the high demand of productivity it is nowadays essential to control the effectiveness of cooling system designs. To get accurate simulation results, it is necessary to use the mathematical model of heat transfer in three-dimensional flows [9,10]. Most injection molding simulation software uses the boundary element method to analyze the heat transfer which is similar to the boundary integral formulation [11,12]. In this study an injection molding analysis is presented showing the heat flow ruling in an injection mold particularly at the corner geometry.

2. Experimental

2.1. Mathematical model

The mass, momentum and energy conversation governing equations for the non-isothermal, generalized Newtonian fluid are given by Eqs. (1)–(10):

Continuity Equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{u}) = 0. \tag{1}$$

Momentum Equation:

$$\rho\left(\frac{\partial \vec{u}}{\partial t} + \vec{u} \cdot \nabla \vec{u}\right) = -\nabla p + \eta \nabla^2 \vec{u} + \rho \vec{g}. \tag{2}$$

☆ Communicated by W.J. Minkowycz.

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doi:10.1016/j.icheatmasstransfer.2011.08.007