Flow-induced Orientation in Shear Flow and Injection Molding of Semi-crystalline Polymer

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Abstract

In this work a two-phase model is used to describe the evolution of crystallinity and orientation in shear flow. The model was also used to simulate the crystalline orientation distribution across the thickness of an injection-molded part. Model results were validated by comparison with literature experimental data for an isotactic polypropylene.

Introduction

In injection molding of semi-crystalline polymers, the molten polymer undergoes shear deformation during or before crystallizing, resulting in flow-induced crystallization (FIC). The basic features of FIC include an enhanced crystallization rate and the formation of oriented crystalline structures. As a result, multi-layered skin-core structures have often been observed in injection molded parts. While a spherulitic structure is often seen in the shear-free core region of an injection-molded product, oriented shish-kebab structure is found at the high shear rate region near the cavity wall [1]. The oriented microstructure leads to a local anisotropy of thermal and mechanical properties, which may cause anisotropic shrinkage in the final products.

We have recently presented a constitutive model for FIC of semi-crystalline polymer melts [2]. Following the approaches of Doufas et al. [3], Eder and Janeschitz-Kriegl [4] and Coppola et al. [5], we describe the polymeric liquid by a FENE-P fluid for the amorphous phase and a rigid dumbbell model for the semi-crystalline phase, respectively. We assume that the free energy change resulting from the flow is the driving force for the enhanced crystallization process.

This paper will apply the model to simulate flow-induced crystallization in a shear flow and in injection molding.

Theory

In the following, a brief description of the model used in the work is given. Further details on the model can be found elsewhere [2].

Crystallization Kinetics

Following the work of Kolmorgoroff [6] we calculate a fictive volume fraction. Let the rate of growth of the spherulite radius as a function of time be G. We assume that the spherulite begins growing from an initially small nucleus at time s. The radius at time t is then given by $\int_s^t G(u)\,du$. The spherulite volume at time t is $\frac{4\pi}{3}\left[\int_s^t G(u)\,du\right]^3$, and this may be generalized to the case of non-spherical growth as follows $g_m\left[\int_s^t G(u)\,du\right]^m$, where m is a constant, and g_m a constant depending

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