Composites: Part A 62 (2014) 77–86

Contents lists available at ScienceDirect

Composites: Part A

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

Prediction of short glass fiber orientation in the filling of an end-gated plaque

Kevin J. Meyer [a,*], John T. Hofmann [b], Donald G. Baird [a]

[a] Department of Chemical Engineering, Virginia Tech, Blacksburg, VA 24061, United States
[b] Macromolecule and Interfaces Institute, Virginia Tech, Blacksburg, VA 24061, United States

ARTICLE INFO

Article history:
Received 13 June 2013
Received in revised form 25 December 2013
Accepted 28 December 2013
Available online 6 March 2014

Keywords:
A. Glass fibers
C. Computational modeling
E. Injection molding

ABSTRACT

This work is concerned with predicting short ($L \leq 1$ mm) glass fiber (SGF) orientation generated during the filling of an end-gated plaque (EGP). Previous EGP simulations have provided results only within the mold cavity and only along the centerline of the mold and made assumptions about fiber orientation at the mold entry. This paper reports on a method to simulate the flow in the sprue, gate and mold region (SGM) to obtain fiber orientation predictions within the end-gated plaque using orientation parameters fit to experimental data. Predicted values of orientation are compared to experimental data both along and away from the centerline. It is observed that orientation can be accurately predicted in a three dimensional mold cavity using the strain reduction factor model. Furthermore, initial conditions at the entrance to mold cavity appear to be a function of mold width as well as mold thickness.

© 2014 Published by Elsevier Ltd.

1. Introduction

Short glass fiber composite suspensions are typically processed by injection or compression molding to form a part with a complex layered microstructure [1]. Local variations of fiber orientation are often seen in even the simplest molding geometries and have led to a variation of the properties of the final part [2]. As a result, a large amount of effort has focused on predicting the final orientation of fibers in an injection or compression molded part to optimize the processing conditions and part performance.

Modeling the orientation of concentrated short glass fiber (SGF) systems during mold filling has typically been accomplished through some variant of Jeffery's model [3]. Jeffery described the motion of a single prolate spheroid in a Newtonian fluid in creeping flow. Folgar and Tucker [4] modified Jeffery's model by adding a term based on isotropic rotary diffusivity that was proportional to the velocity gradient to account for fiber–fiber interaction in a concentrated fiber system and weighted by an empirical value, C_I. The fiber interaction coefficient, C_I, has been estimated by fitting experimental data [5], through empirical relationships [6,7] and by fitting transient stress growth at the startup of steady shear [8,9]. The Folgar–Tucker (FT) model has shown good qualitative agreement with experimental data and is thus a popular choice for simulating short glass fiber orientation [5,10].

Stress growth experiments in the startup of simple shear have shown that the orientation of fibers in concentrated suspension evolves more slowly than predicted by the Folgar–Tucker model [11,12]. To more accurately reflect the observed transient fiber orientation a "slip" parameter was suggested by Sepehr et al. [13,14] and Eberle et al. [11] to slow the evolution of orientation. The strain reduction factor (SRF) model proved more accurate in comparison to experimental data but the addition of the slip parameter rendered the SRF model non-objective [15]. Wang et al. [16] developed the reduced strain closure (RSC) model as an objective form of the SRF model where the closure approximation is modified eliminating the objectivity problem while including the slower orientation kinetics observed in experimental values of orientation. Even though the SRF model is non objective it has been shown to be useful in describing the evolution of orientation in simple flows and in more general flows [14,17,18]. Furthermore, Wang et al. [19] showed that the SRF model qualitatively predicted fiber orientation in a rotating compressing and expanding center-gated disk. Phelps and Tucker [20] have developed a form of the RSC model (ARD–RSC) which accounts for the anisotropy in fiber interactions but requires additional fitting efforts in determining six model coefficients. The main thrust of this paper was an attempt to use two of the most widely used models for fiber orientation (RSC and SRF) and assess their ability to predict fiber orientation both along and away from the centerline of the mold.

* Corresponding author. Present address: Department of Chemical Engineering, 133 Randolph Hall, Virginia Tech, Blacksburg, VA 24061, United States. Tel.: +1 941 916 0725.
E-mail address: kjmeyer@vt.edu (K.J. Meyer).

http://dx.doi.org/10.1016/j.compositesa.2013.12.013
1359-835X/© 2014 Published by Elsevier Ltd.

The prediction of short fiber orientation in complex test geometries for injection molding has been the subject of significant work. A number of authors have investigated the prediction of SGF orientation in a center-gated disk geometry and have found reasonable agreement with experimentally obtained values of fiber orientation under different conditions [5,10,21–24]. The prediction of SGF orientation in an end-gated plaque geometry has seen considerably less attention. Altan et al. [25] assumed a planar random inlet condition to a rectangular channel and computed the short fiber orientation using a coupled approach involving both the 4th and 6th order tensors of orientation but did not compare his results to experimental orientation values. Bay and Tucker [5], Han and Im [26] and Nguyen et al. [27] simulated the orientation of glass fibers in an end-gated strip and found reasonable agreement with experimental orientation values but only made comparisons along the centerline of the mold. Gupta and Wang [28] performed a more detailed analysis of an end-gated plaque using a polyester matrix and SGF's and saw reasonable qualitative agreement between predicted values of orientation and experimentally obtained values but no quantitative statement could be made due to course sampling techniques. Thus, there is a need for a more comprehensive and quantitative study of predicting the orientation of SGF's in an end-gated plaque geometry.

Predicting fiber orientation in complex geometries has been shown to be affected by the choice of initial conditions. Previous authors have observed that assumed symmetric initial conditions for fiber orientation produce symmetric orientation predictions [5,23,24]. In contrast, experimentally obtained values for fiber orientation are generally observed to be asymmetric through the mold thickness and thus require asymmetric initial conditions [24]. One method of obtaining asymmetric initial conditions of orientation involves the use of experimental orientation values obtained from the gate mold interface. Velez-Garcia et al. [23] used experimental data as initial conditions for the simulation of fiber orientation to the mold in a center-gated disk and found an increased agreement with experimental orientation values when compared to an assumed orientation. The drawback to this method is that it requires experimental knowledge of the system that is being predicted (to predict the orientation of fibers in a system experimental data must first be obtained and analyzed from that system). To address this concern, Chung and Kwon [24] suggested simulating the entire mold of a center-gated disk (sprue and mold) as a single domain and saw a similar increase in agreement between predicted values of orientation and experimental data for a SGF system as Velez-Garcia et al. [23] but did not require experimental orientation values. Meyer et al. [21] built on the work of Chung and Kwon [24] and developed the sprue-gate-mold (SGM) method for the prediction of orientation of long glass fiber suspensions in the center-gated disk and observed an increase in agreement between model predictions and experimental data again without the need for experimental orientation values at the gate/mold interface.

The purpose of this work is to predict short glass fiber orientation in an end-gated plaque including gate effects, the advancing front and temperature effects and compare the results with experimentally obtained values of short glass fiber orientation both along and away from the centerline of the mold drawing conclusions as to the accuracy of the predictions. Furthermore, it will be determined if objectivity plays a role in predicting SGF orientation throughout the end-gated plaque by solving both the SRF and RSC models throughout the geometry. The fiber orientation predictions are performed using the decoupled approach for the stress and orientation tensors [22,29,30]. A volume of fluid finite element method is used in the ANSYS Polyflow environment to calculate the velocity gradients of a non-isothermal generalized Newtonian fluid filling an end-gated plaque geometry incorporating both the gate region and advancing front. The solutions of the SRF and RSC fiber orientation models are calculated through a combination of MATLAB and C routines in the MATLAB environment. Fiber orientation predictions are carried out using orientation parameters (κ and C_I) obtained through fitting transient stress data from shear flow experiments and through fitting experimental data obtained from injection molding experiments.

2. Governing equations

2.1. Flow and heat equations

The flow was assumed laminar ($\mathrm{Re} \approx 10^{-3}$) and incompressible resulting in the equations of continuity and motion as given in Eqs. (1) and (2), respectfully:

$$0 = \nabla \cdot \bar{v} \tag{1}$$

$$0 = -\nabla P + \nabla \cdot \bar{\bar{\tau}} \tag{2}$$

In Eqs. (1) and (2), $\bar{v}$ is the velocity vector, P is the isotropic pressure and $\bar{\bar{\tau}}$ is the extra stress tensor.

Temperature was also taken into account in the simulations using Eq. (3) where ρ is the density, $\overline{C}_P$ is the specific heat capacity per unit mass, DT/Dt is the material derivative $(\partial T/\partial t + \bar{v} \cdot \nabla T)$, k is the thermal conductivity, $\dot{\bar{\bar{\gamma}}}$ is the rate of strain tensor and $\bar{\bar{\tau}}$ is the extra stress tensor:

$$\rho \overline{C}_P \frac{DT}{Dt} = k \nabla T + \bar{\bar{\tau}} : \dot{\bar{\bar{\gamma}}} \tag{3}$$

The viscosity of the matrix was also dependent on the temperature of the system and is included through the use of an Arrhenius law relation shown in Eq. (4) where $\alpha = E_a/R$ and T_α is a reference temperature:

$$\eta(T) = \exp\left[-\alpha\left(\frac{1}{T} - \frac{1}{T_\alpha}\right)\right] \tag{4}$$

For the duration of the work presented here the fluid is assumed to have constant thermal conductivity and heat capacity. The parameters for Eqs. (3) and (4) are given in Table 1.

2.2. Extra stress tensor representation

The decoupled approach for the solution of the stress and orientation tensors was used based on previous work by Chung and Kwon [24], Eberle et al. [8], Ortman et al. [9] and Mazahir et al. [22] which suggests there is no consistent representation of the stress tensors which includes both fiber loading and fiber–fiber interaction for concentrated suspensions. The effect of fibers was included by incorporating the fiber loading and fiber–fiber interaction contributions into the simulations through the values of κ and C_I so that only the neat matrix properties are used to predict the

Table 1
Material properties for non-isothermal finite element simulation.

Parameter	Value
ρ (kg/m^3)	1100
η_0 (Pa s)	4814
λ (s^{-1})	0.2777
n	0.909
C_P (J/kg K)	2800
k (W/m K)	0.234
α (K)	4220
T_α (K)	427.23
T_{wall} (K)	363
T_{inlet} (K)	463

Download English Version:

https://daneshyari.com/en/article/1466051

Download Persian Version:

https://daneshyari.com/article/1466051

Daneshyari.com