Rheology Studies of Polyethylene/Chemical Blowing Agent Solutions Within an Injection Molding Machine

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An in-line capillary rheometer nozzle equipped to a conventional reciprocating 55-ton injection molding machine was used to study the viscosity of single phase low density polyethylene (LDPE)/chemical blowing agent (CBA) solutions under high shear rate in the concentration range of 0 to 5 wt%. The steady shear viscosity of LDPE with endothermic and exothermic chemical blowing agents was measured for shear rates ranging from 170 to 200,000 s^{-1} and under pressure conditions up to 36 MPa. Pressure-volume-temperature (pvT) measurements were determined to account for the pressure effects and the changes of the free volume during processing. The viscosity reduction of the polymer-CBA solution was found to be dependent on the concentration of the chemical blowing agent and melt pressure. A model based on a simplified Cross-Carreau model, incorporating the pvT behavior of LDPE, and the free volume concept was proposed to estimate the viscosity reduction resulting from the addition of a chemical blowing agent. The model employs a scaling method based on concentration-dependent and pressure-dependent shift factors to collapse the viscosity measurement to a master curve at each temperature. POLYM. ENG. SCI., 45: 1108–1118, 2005. © 2005 Society of Plastics Engineers

INTRODUCTION

Polymeric structural foams have been widely used in automotive, aerospace, construction, electronic, and packaging industries, because of their low density, high impact strength, and insulation properties. However, recent market pressures on processors to generate thinner, more complex part geometries have highlighted the lack of fundamental understanding and control inherent to foam processing. For the manufacture of thinner parts, high injection speeds and good flow characteristics are needed, requiring knowledge of the rheological properties of the thermoplastic/blowing agent mixtures at all stages throughout the injection molding process. Predictive rheological models of a gas/molten polymer solution are essential for the optimization of the processing conditions, development of numerical simulation regarding foam processing, and the development of new foam compounds and process technologies.

In recent years, more attention has been focused on the accurate measurement of the reduced viscosity of a polymer solution containing a dissolved gas [1–3] to better understand the foaming process. The viscosity of gas-polymer solutions cannot be measured by standard methods since the concentration of the blowing agent must be determined precisely and kept constant within the chosen rheology-measuring instrument. In off-line measurements, a gas-polymer solution can be charged into the rheometer from an equilibrium vessel while being maintained at a high pressure and temperature. Mendelson [4] designed a pressurized chamber at the exit of a plunger-type capillary viscometer in order to prevent bubble formation. Both Gerhardt et al. [5, 6] and Kwag et al. [7] measured the viscosity reduction of different polymer/CO_2 solutions by using a sealed high-pressure capillary rheometry with separate loading and back pressure assemblies. Sato et al. [8] devised a new viscometer for gas-polymer solutions that consisted of twin opposed piston-cylinders, a capillary, and a hydraulically controlled pressure device. The maximum shear rates achieved in off-line rheometers have been reported in the order of 1000 s^{-1}. However, the equilibration of the melt with gas addition in these high-pressure rheometers can be quite complicated and time consuming. In addition, the amount of material charged into an off-line rheometer tends to be quite limited. Therefore, the results may not be applicable to large processing equipment.

In contrast to off-line devices, in-line rheometers are more capable of obtaining accurate rheological information of the polymer melt under conditions pertinent to the actual

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