Polymer Melt Rheology for Better Processing Conditions

Masataka Sugimoto and Kiyohito Koyama*

Jonan 992-8510, Yamagata University

koyama@yz.yamagata-u.ac.jp

Abstract. A large number of studies have been made on the shear flow behaviors of polymer solutions and melts. The flow properties can be correlated with the flow in a channel for injection molding and extrusions, and therefore seen in many reports not only by the academic researchers but also by manufactures and fabricators. Only this behavior is, however, insufficient to provide the whole picture between the flow or deformation behavior and the processability of the polymer melts. We often have experienced a discrepancy with the fact that any one of the polymers with comparable shear flow behavior shows better processability. This can be, in many cases, attributed to the different chain deformation behavior under shear-free flows when the polymer melts undergoes the free-surface process in which the shape and thickness of the extrudate are determined by the elongational rheology behavior. Then we have carried out research on the rheology control of polymer liquids to improve the processability. In our early studies, the elongational viscosity was determined by in-situ measurements of diameters along the spinline and tension during the spinning process. The temperature dependency of elongational viscosity showed Arrhenius-type relationship. It was found that the obtained results meant the constant activation energy for flow and three-fold value to that of the shear flow. However, the complex experiments leaded to considerable scattering due to the non-isothermal and non-constant rate conditions, and non-Newtonian properties of the polymer liquids unlike with Newtonian liquids. We developed elongational rheometer which enabled the polymer melts to achieve constant strain rate under the isothermal environment. Since then we have made a great deal of efforts on the elongational flow measurements of various polymers in terms of molecular weight, molecular weight distribution, chemical composition, polymer blends, miscibility and chain architecture. Through the investigations we mainly focused on a presence of a small amount of ultra-high molecular weigh components and highly branching chains from the viewpoint of a spiky long relaxation time mode in the relaxation time distribution. For example polystyrene incorporated with ultra-high molecular weight analogs showed more significant increase of elongational viscosity at large strain as increasing the content. This cannot be expected for immiscible polymer pairs, resulting in macroscopic phase separation. The most prominent example may be polypropylene. Polypropylene is one of typical linear polymer and known to have difficult processability under free-surface due to a drawback of insufficient melt strength. We addressed the control of the rheology based on our concept of a small amount of long relaxation time mode and successfully achieved an enhancement of the elongational flow behavior. The high melt strength polypropylene showed distinguished foaming and blow molding processabilities without a remarkable change of the shear flow behavior related to flow in the channel of the extruder. Thus, we have worked on the rheology control of various polymer liquids and these results have been utilized in the fields of automobiles, ICT, packaging, industrial components, construction, food and daily commodities. Here we will discuss the importance of the elongational flow by providing the specific examples of polymer processings such as fiber spinning, blow molding, foaming, film (or sheet) extrusion and low-pressure transfer molding.

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