142aw Experimental Study of Slip Flow in the Semi-Hyperbolically Converging Dies

Prajakta A. Kamerkar and Brian J. Edwards

Elongational flow fields are of immense importance in the polymer processing industry as the elongational flows are widely used in processes such as fiber spinning, film blowing, melt drawing, etc.[1] The elongational flow produces the desired degree of polymer orientation so that the final products have the target properties such as toughness and durability. Although such polymer processing processes are widely used, it is very difficult to characterize the rheological properties of polymers such as elongational viscosity. This can be attributed to the difficulty in developing the experimental methods for measuring the elongational flow properties. In late 1990s, Collier and co-workers began work on a project aimed at developing an inexpensive, reliable, accurate and simple to use device to measure the elongational viscosity of polymer melts in a uniaxial elongational field. They have developed the semi-hyperbolically converging dies[2,3], the shape of which follows the natural pathways of the streamlines required to produce a pure uniaxial elongational field provided the assumptions used in the theoretical development are satisfied. We have continued the work with the semi-hyperbolically converging dies developed by Collier and co-workers. This research focuses on analyzing the assumptions used in the development of these dies.

The semi-hyperbolically convergent dies are used to measure the effective elongational viscosities of polymer melts and solutions at the industrial processing conditions. Based on a recent study using finite element analysis by Feigl et al.[4], it was confirmed that when full slip was assumed at the die walls in the semi-hyperbolically convergent dies, one can essentially obtain a purely uniaxial elongational flow. Hence the degree of slippage taking place in these dies was scrutinized experimentally in our research. The experimental study was based on the knowledge that small amounts of carboxylic acid additives can greatly reduce the shear viscosity in many thermoplastic polymer melts.[5] Stearic acid was added to various thermoplastics such as polypropylene (PP), low-density polyethylene (LDPE), and high-density polyethylene (HDPE) in various amounts to study the slip. We used the Mooney analysis[6] to quantify the slip in capillary dies for various thermoplastics such as PP, LDPE, and HDPE. The Mooney equation was then modified to fit the semi-hyperbolically convergent dies. Experiments were performed to quantify the degree of slip in both the capillary and the semi-hyperbolically convergent dies.

We used capillary dies of varying diameters ranging from 0.9 - 2mm and semi-hyperbolically convergent dies of different Hencky values (4, 5, 6 and 7 Hencky strain). We have observed shear stress reduction upto about 50% with a small amount of stearic acid added to the polymer melt. The degree of stress reduction was not strongly dependent on the stearic acid concentration; we studied three different weight percentages namely 1, 2 and 5%. Experiments using the semi-hyperbolically converging dies exhibit viscosity reduction on the order of only 10-15% at most at lower Hencky values. As the Hencky value of the die increases, the pure sample experiences more slip in the die and hence the degree of reduction decreases. The neat polymer melts experience a much greater degree of slip in the semi-hyperbolically converging dies than in shear flow.

This work corroborates the fact that neat polymer melts experience greater slip at the walls of the semi-hyperbolically convergent dies than in capillary dies. Also the semi-hyperbolically convergent dies give a good approximation of purely elongational flow at high Hencky strains, which is applicable to the polymer processing operations such as fiber spinning. Hence from the computational results of Feigl et al. and the present experimental work, we can say that the semi-hyperbolically convergent dies are a good tool for measuring the elongational viscosities of polymer melts.

References

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