INTERCOMPARISON OF HIGH RATE CAPILLARY EXTRUSION RHEOMETRY RESULTS FOR A RANGE OF POLYMER MELTS

M. Rides[1], A. Kelly[2], C.R.G. Allen[1]

1 - National Physical Laboratory
2 - University of Bradford

martin.rides@npl.co.uk

Manufacturing of small-scale components and products, and components and products with micro-scale features by micro-moulding is becoming increasingly important. However, properties data for reliable design obtained at relevant conditions are not readily available. In micro-moulding, shear rates up to and in excess of 10^5 s^{-1} are reported in the literature [1]. Thus for reliable flow simulation of the micro-moulding process there is a need for rheological data at such high shear rates. The implications of extrapolating shear viscosity data by several decades in shear rate on the accuracy of flow simulations are significant. Shear viscosity data at such high rates, however, are of limited availability. This is often due to limitations in measurement equipment capability [2], related to the maximum achievable piston speed, the instrument maximum load bearing capacity, pressure transducer upper limits and the availability of dies of sufficiently small diameter: all potentially limit the maximum achievable shear rates for a given fluid. Furthermore, the precision of the high shear rate shear viscosity data is normally not known.

This paper addresses the measurement of the shear viscosities of a range of thermoplastic polymers at high shear rates using extrusion techniques. A range of materials were tested: a low density polyethylene (LDPE), a high density polyethylene (HDPE), a polypropylene (PP), and a polystyrene (PS). Measurements were made using two laboratory extrusion rheometers and an instrumented Fanuc Roboshot moulding machine. A comparison of results from the various instruments is made, and the precision of results and potential sources of error are discussed. Measurements were also made with rotational rheometers, providing further comparison and validation of results at lower shear rates.

A comparison of high rate extrusion rheometry results demonstrated an overall good level of agreement for shear viscosities up to shear rates of 2 x10^5 s^{-1}, with results varying typically by up to no more than $\pm$ 20%, which is very favourable compared with the reproducibility value of $\pm$ 28% (95% confidence level) for capillary extrusion rheometry measurements at lower shear rates as reports in the standard ISO 11443 [3]. At even higher shear rates, for example above a shear rate of 360000 s^{-1} for PS, deviations from the preceding shear thinning behaviour were evidenced; the origins of which are discussed. Shear viscosity measurements carried out using rotational rheometers showed very good agreement at lower shear rate thus providing further independent validation of the extrusion results. A significant source of error due to leakage of sample past the piston at the high pressures experienced, accounting for a factor of x10 error in measured shear viscosity, was successfully addressed through equipment modification.

1 U.M. Attia, A.E. Jeffrey, R. Alcock, An evaluation of process-parameter and part-geometry effects on the quality of filling in micro-injection moulding, Microsyst. Technol. (2009) 15:1861–1872.

2. C.S. Chen, Rheological behaviour of low/high density polyethylene melt flowing through micro-channels, E-POLYMERS 039, MAR 11 2008.

3. ISO 11443 Plastics -- Determination of the fluidity of plastics using capillary and slit-die rheometers