CMMT(MN)040

Extensional Flow Properties Of Polymer Melts Using Converging Flow Methods

Summary

In many forming processes the polymer melt undergoes predominantly extensional deformation, for example in blow moulding and film blowing. Furthermore, the extensional flow behaviour of melts differs significantly from their shear flow behaviour. Thus extensional flow measurement methods are necessary to characterise most appropriately the melt behaviour. Such data can be used for the development and selection of materials and for improving processing.

There are two basic approaches to determining extensional flow properties of polymer melts: either using tensile testing methods or converging flow methods. Tensile testing methods were reviewed and their use reported elsewhere [1,2]. The converging flow approach for determining the extensional flow behaviour of polymer melts is based on the measurement of the resistance to flow in a contraction geometry. A converging flow is, by definition, a type of extensional flow. It is expected therefore that extensional viscosity might be obtained from the measurement of pressure drop and flow rate in a converging flow. The approach of using converging flow methods is appealing as experimental data are easily obtained from capillary extrusion rheometry tests that are normally carried out to determine the shear viscosity of materials. Thus extensional viscosity values can be obtained from the same capillary rheometry tests that are carried out to determine shear viscosity at little or no extra cost.

This measurement note summarises work carried out on the use of converging flow models for determining extensional viscosity data. A comparison of the predictions of selected converging flow models is presented. Also, a comparison of the predictions of the Cogswell converging flow model with data obtained using a tensile method is presented to demonstrate the validity of the converging flow approach.

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April 1999

The Converging Flow Method

The converging flow method can be used to assess the extensional flow behaviour of polymer melts.

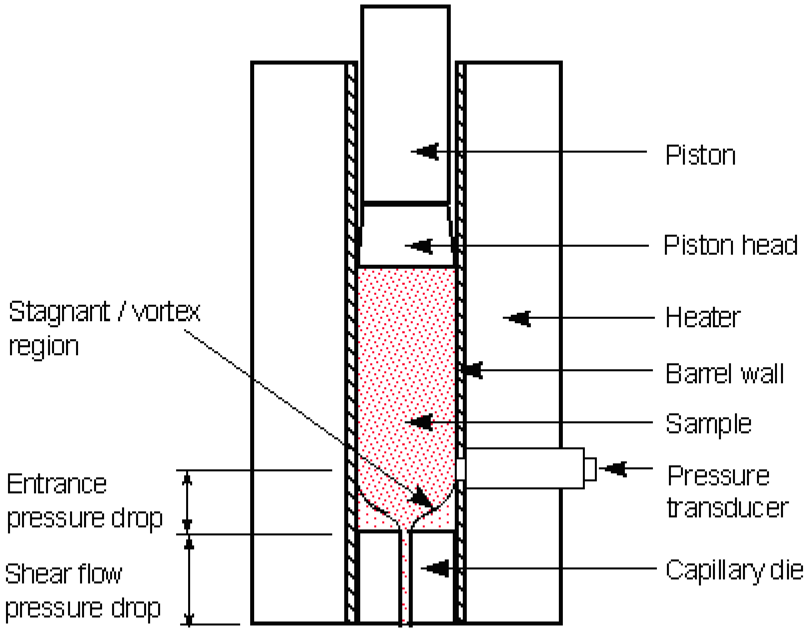

Figure 1: Converging flow in a capillary extrusion rheometer

The basis of the method, detailed in [3], is to measure the pressure drop in the entry region to the capillary extrusion rheometer die, commonly referred to as "entrance pressure drop", Figure 1. This can be simply done by using at least two dies of different length, but of the same diameter. The extrusion pressure data for the two dies, for a given flow rate, is then extrapolated to a die length of zero, Figure 2. The value of extrusion pressure for a die length of zero is taken to be the entrance pressure drop. Entrance pressure drop data as a function of flow rate, combined with shear viscosity data also obtained from these tests, can then be used to determine extensional viscosity values.

It has been observed that entrance pressure drop data can be a more sensitive measure of differences in materials than shear viscosity data [2,3]. Therefore their use, without resorting to their interpretation as extensional viscosity data, can be of significant value for quality control type activities.

To interpret the experimental data obtained from capillary extrusion measurements as extensional viscosity data there are several converging flow models that have been developed. A critical review of these models is presented elsewhere [4]. The review assessed the models and their use. The review can be used to source information on converging flow testing on a range of polymer melts.

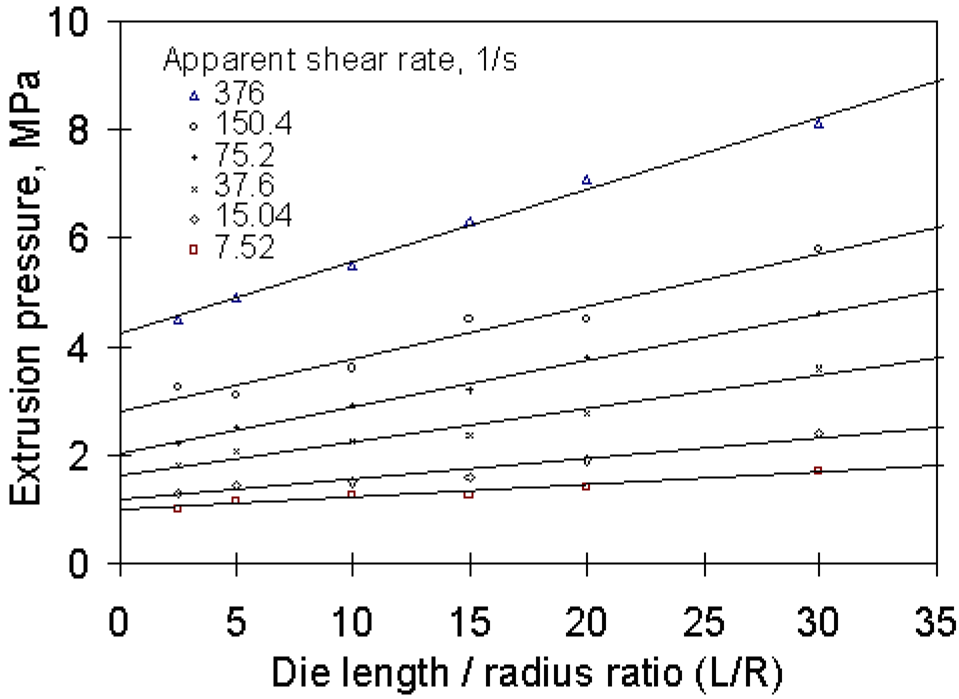

Figure 2. Bagley plot used for the determination of entrance pressure drop and shear viscosity values of a glass fibre filled thermosetting plastic at 50°C

The main advantages and disadvantages of converging flow methods are as follows. The necessary experimental data for analysis using converging flow models are simply obtained from capillary extrusion rheometry measurements at little or no extra cost above that needed to obtain shear viscosity data. However, there is a degree of uncertainty in the interpretation of such data using relatively simplistic models that necessarily require assumptions to be made in order to interpret the experimental data in terms of extensional viscosities. The models assume an equilibrium extensional viscosity behaviour whereas polymer melts exhibit behaviour in extension that is normally transient, i.e. a function of strain and time. Converging flow methods cannot be used easily to determine strain hardening behaviour as the models assume equilibrium extensional viscosities. Thus strain hardening cannot be directly deduced. However, the use of different contraction ratios could potentially be used to investigate strain hardening. In favour of converging flow methods is that very high strain rates are possible, compared with tensile methods that tend to have an upper limit of $\approx$ 10 s^{-1}. Furthermore, the process of calculating extensional viscosities, given a converging flow model, is itself not particularly difficult. The method also closely mimics many processing methods. It is preferable to use techniques that mimic the processes for which the data are being sought. In so doing the testing conditions more closely match the conditions experienced in processing, and thus the data are likely to be more relevant. The converging flow method, being an extrusion method, is widely applicable in the polymer processing sector as many processes are based on extrusion.

Extensional Flow Behaviour of Polymer Melts Using Converging Flow Methods

To assess the validity of the converging flow approach for determining extensional viscosity data a comparison of data obtained by converging flow with that obtained using a tensile testing method has been made [3]. Three materials: a high density polyethylene, a low density polyethylene and a linear low density polyethylene were chosen as they exhibited quite different strain hardening characteristics. Predictions for a LLDPE obtained using various converging flow models are presented in Figure 3.

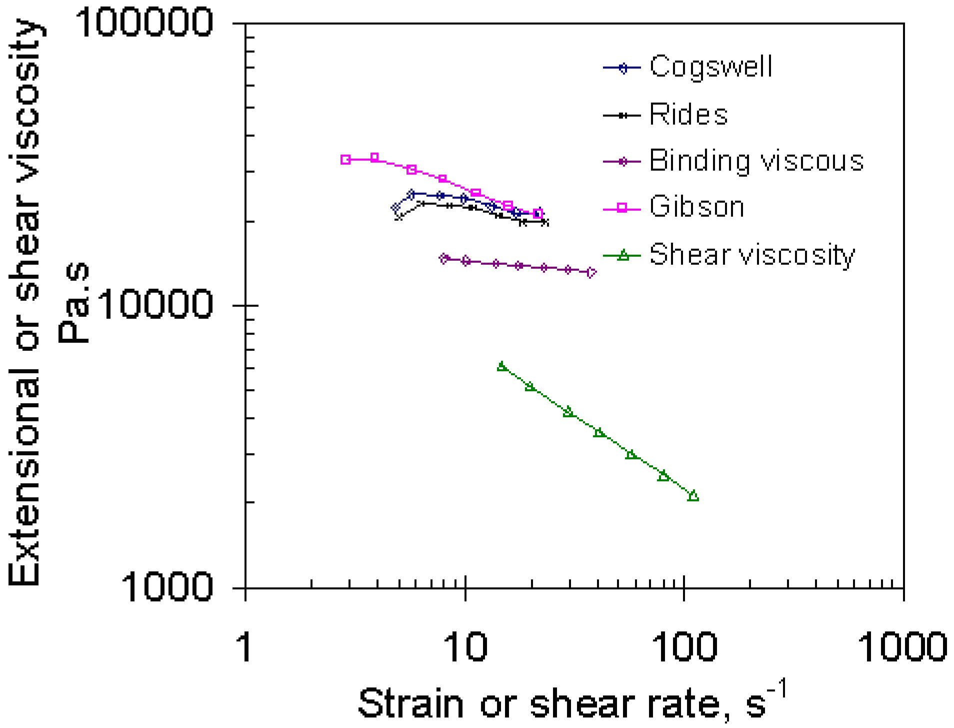

Figure 3: Comparison of predictions of the converging flow models for an LLDPE (HGF000) at 150°C. Points on the Binding plot are for identification only rather than indicating actual data points

There are considerable difficulties in comparing data from converging flow analyses with those from tensile stretching methods, principally due to the transient nature of the extensional viscosity behaviour [3]. One approach is to compare the converging flow predictions with the maximum value of the tensile stress growth coefficient values obtained at each strain rate, Figure 4. The resultant plot shows good agreement of the data from the two methods for LDPE and HDPE - to within 30 - 40%. The discrepancy for LLDPE was greater with the converging flow predictions being ? 50% lower.

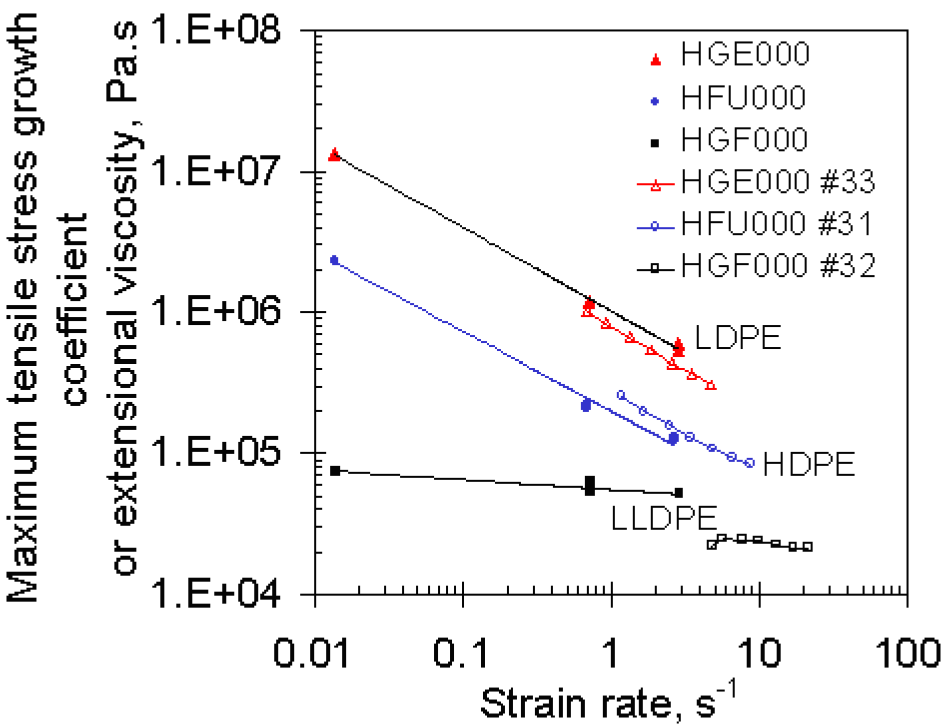

Figure 4: Comparison of extensional viscosities determined using the Cogswell converging flow model

(open points) with maximum tensile stress growth coefficient values obtained by a stretching method (solid points) LDPE (HGE000), LLDPE (HGF000) and HDPE (HFU000) at 150°C.

It was concluded on the basis of the data presented in [3] that the Cogswell model yields better agreement with the tensile stretching data than the other models.

Conclusions

Despite the problems with, and limitations of the converging flow method the technique has considerable benefits as a materials characterisation method:

- it can provide valuable information on the extensional flow behaviour of melts,
- it is relatively simple to use,
- if capillary extrusion rheometry is to be used to determine shear flow behaviour then entrance pressure drop data and thus extensional viscosity data can be obtained at minimal additional cost, and
- reasonable agreement between converging flow and stretching methods has been demonstrated.

A guide [3] describing the method for determining the extensional flow behaviour of plastics melts using converging flow models is available from NPL. It:

- gives advice on how to obtain extensional viscosity values of polymer melts from measurement of the pressure drop in capillary die extrusion tests,
- defines good practice in the generation of shear viscosity and entrance pressure drop data to input into the models,
- presents an assessment of the effect of errors in the entrance pressure drop and shear viscosity data on the derived extensional viscosity values, and
- compares the predictions of the selected converging flow models and compares predictions with data obtained using a tensile testing method for select materials, thereby demonstrating the validity of the converging flow approach.

Acknowledgement

This measurement note was prepared as part of a project on the measurement of the extensional viscoelastic properties of polymers. This project was carried out as part of a programme of underpinning research financed by the Engineering, Automotive and Metals Division of the DTI.

References

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