

Computer Modelling of Polymer Processing

An EPSRC Engineering Network
*in conjunction with the Polymer Processing and Engineering Committee of the
Institute of Materials*

International Conference
at
Materials Congress 2000

Friday 14 April, 2000
Cirencester, UK

Constitutive Equations for Polymer Melts and Rubbers Lessons from the 20th Century

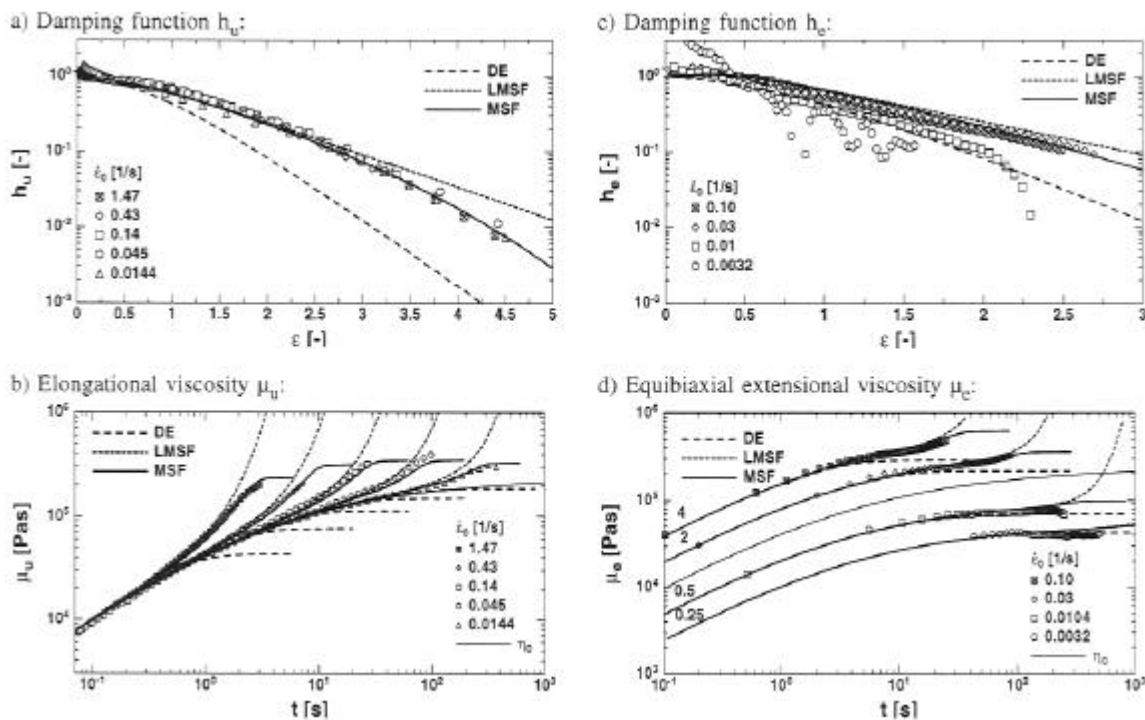
Manfred H. Wagner

*Polymertechnik/Polymerphysik, Technische Universität Berlin, Fasanenstr. 90,
D-10623 Berlin, Germany*

Refinements of classical theories for entangled or crosslinked polymeric systems have lead to incommensurable models for rubber networks and polymer melts, contrary to experimental evidence, which suggests a great deal of similarity. Uniaxial elongation and compression data of linear and branched polymer melts as well as of crosslinked rubbers were analyzed with respect to their nonlinear strain measure. This was found to be the result of two contributions: (1) affine orientation of network strands, and (2) isotropic strand extension. Network strand extension is caused by an increasing restriction of lateral movement of polymer chains due to deformation, and is modelled by a molecular stress function f , which in the tube concept of Doi and Edwards is the inverse of the relative tube diameter. Up to moderate strains, f^2 is found to be linear in the average stretch for melts as well as for rubbers (the Linear Molecular Stress Function Theory), which corresponds to a constant tube volume. At large strains, rubbers show maximum extensibility, while melts show maximum molecular tension f_{\max} . This maximum value of the molecular stress function governs the ultimate magnitude of the strain-hardening effect of linear and long-chain branched polymer melts in extensional flows^{1,2}.

The figures show damping functions and extensional viscosities (symbols) of a polystyrene melt in uniaxial elongation and equibiaxial extension³. Lines are predictions using the Doi-Edwards (DE) model, the Linear Molecular Stress Function (LMSF) theory, and the one-parameter Molecular Stress Function (MSF) theory with $f_{\max}=3.6$.

1. Wagner M.H., P. Ehrecke, P. Hachmann, J. Meissner (1998) *J. Rheol.* **42**, 621-638
2. Wagner M.H., H. Bastian, P. Ehrecke, M. Kraft, P. Hachmann, J. Meissner (1998) *J. Non-Newt. Fluid Mech.* **79**, 283-296
3. Wagner M.H., H. Bastian, P. Hachmann, J. Meissner, S. Kurzbeck, H. Münstedt, F. Langouche (2000) *Rheol. Acta* in press



CFD and flow visualisation for polymer melt contraction flows

COMPRO paper 1

CFD of polymer melts has focussed on viscoelastic simulation using constitutive models of the time-integral type. This area is complemented by experimental measurements using new techniques that are being developed at Bradford.

Viscoelastic simulation has focussed on 'separable' KBKZ constitutive models, of the type introduced by Wagner [1]. In-house finite element code has been developed for 2D and axisymmetric flows employing 9 node bi-quadratic elements for velocity components, and bi-linear elements for pressure. A number of different constitutive models are implemented, and several alternative strategies for stress calculation, velocity field adjustment and other fundamental procedures are incorporated. In order to match the strain-hardening observed in polymers such as LDPE, a modified form of damping function has been developed that essentially employs a function of a single, invariant, measure of strain. This permits the high normal stress levels measured in planar contraction flows of LDPE melt (and associated features such as vortex growth, and enhanced die-swell) to be simulated.

Experimental studies were performed on a low density polyethylene flowing through a planar abrupt contraction die with a 5:1 contraction ratio. Particle streak velocimetry and particle image velocimetry techniques were employed to measure two components of the velocity in the die. Laser sheet lighting was used to improve the measurements by allowing the measurement of the velocity of the particles in a known plane. The main motivation for the experimental work is to provide data in a form that may be compared directly with the numerical predictions produced by finite element methods to facilitate the determination of a quantitative measure of error in the prediction. Figure 1a represents a single video frame available for PSV. Measurements made from single frames exhibit significant quantities of noise and relatively little data can be deduced in the vortex. Strategies to automate the data collection and analysis processes have been implemented, allowing greater quantities of data to be analysed in an acceptable time period. A least squares method has been employed to fit the data to a triangulation of the flow domain. A sub-division of the quadrilateral elements used in the numerical simulations was used to construct this triangulation. Figure 1b shows a larger data set fitted to the mesh. Further processing allows contours of streamfunction to be deduced from the experimental data (Figure 1c).

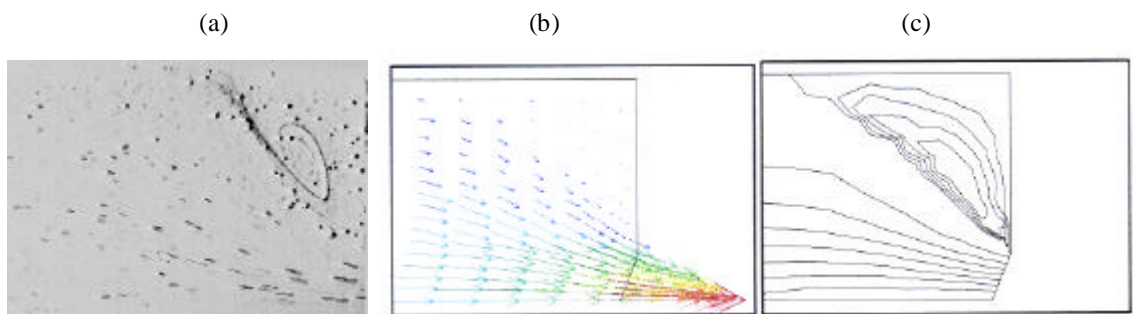


Figure 1 Intermediate results in processing experimental PSV data: (a) single video image, in negative, showing illuminated particles, (b) velocity vectors, on a regular mesh, computed from least-squares fitting 10^5 experimental velocity vectors to a finite-element grid, and (c) contours of constant streamfunction computed from data shown in (b).

Results will be presented for experimental measurements on Dow 150R LDPE, along with comparisons with numerical simulation.

References

1 Wagner M.H., *J.Non-Newt.Fluid Mech.*, **4** (1978) p39-55

A Lagrangian flow solver for complex flows in polymers

COMPPRO paper 2

T M Nicholson, O G Harlen+, T C B McLeish**
** IRC in Polymer Science and Technology*
+ Department of Mathematics
University of Leeds, Leeds LS2 9JT

The transient flow of a branched polymer melt through various contraction geometries has been modelled using a molecularly based constitutive equation together with a Lagrangian finite element method and compared to experimental data.

The constitutive equation, developed by McLeish and Larson, models the polymer as a suspension of idealised "pom-pom" molecules consisting of a cross-bar connecting two identical stars. The constitutive parameters directly relate to features in this structure. Initial simulations used a set of parameters corresponding to mono-disperse Pom-Pom molecules, but the program has now been extended to use a multi-mode extension of the Pom-Pom model, with parameters that vary with the degree of branching. The parameters in this model can be obtained by a simultaneous fit to transient shear and extension experimental rheological data.

The flow of the polymer was calculated using a finite element method with a moving triangular grid. At each time step the velocity and pressure were calculated from the current values of the constitutive parameters. The constitutive parameters, and positions of the grid vertices were then updated using the calculated data. This "flowSolve" program can produce various outputs, including the visualisation of the development of vortices upstream of the contraction and of the birefringence - both of which may be compared with direct experimental observations.

Geometries considered include flow through a contraction, die swell upon emerging from a die, and flow through a constriction. In each case a comparison can be made with experimental observations of the polymers parameterised.

3D FEA of gas assisted injection moulding using a pseudo-concentration method

L. Johnson, P. Olley and P. D. Coates.

*IRC in Polymer Science and Technology. Dept. of Mechanical and Medical Engineering.
University of Bradford. West Yorkshire. BD7 1DP. UK*

Abstract

The gas assisted injection moulding (GAIM) process has benefits realised through material saving, improved product performance and lower capital cost of machinery. This important process is similar to conventional injection moulding in so far as polymer melt enters a cavity under pressure. However, before the melt completely fills the cavity, nitrogen gas is introduced into the melt at high pressure to complete the filling stage. Gas pressure is maintained to replace the packing pressure during cooling, normally supplied by the melt injection unit.

Modelling of the GAIM cavity filling stage has used a variety of methods adapted from the widely used 2-D approach used for conventional injection moulding. Although these methods have been useful for rough predictions in mould filling without requiring excessive computational power, crucial information is missing regarding the final distribution of polymer and gas in any given cross section. Only true 3-D modelling techniques can provide the necessary information regarding the cross sectional form in a gas channel to determine residual wall thickness and bubble penetration. Presented here is a 3-D finite element implementation of a pseudo-concentration method.

A fixed finite element grid is used to mesh the cavity. After each time step calculations of velocities in the x, y and z directions (u, v, w), pressure (p) and concentration (c) are made. The pseudo-concentration method uses a material label, or concentration (c), to distinguish between the polymer and gas; gas is $c_{\text{gas}}=0$ and polymer is $c_{\text{polymer}}=1$. The concentration value at each node is rounded to c_{gas} or c_{polymer} after each time step, except at the nodes bordering an element where the concentration contour of $c=0.5$ passes; this represents the polymer/gas interface. The exact location of the polymer/gas interface can therefore be interpolated and the residual wall thickness predicted from these modelling results.

A typical simulation result is shown in figures 1 and 2, which only show the concentration contours representing the polymer and clearly show the formation of the gas bubble inside the specimen. Figure 1 shows a cross-section of our test specimen near the beginning of the 200mm uniform gauge length. Figure 2 shows contours along the centreline (lengthways) of the specimen.

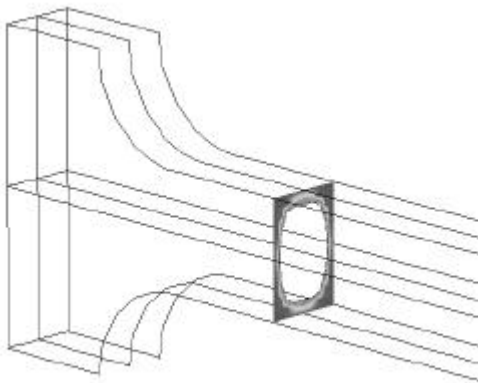


Figure 1

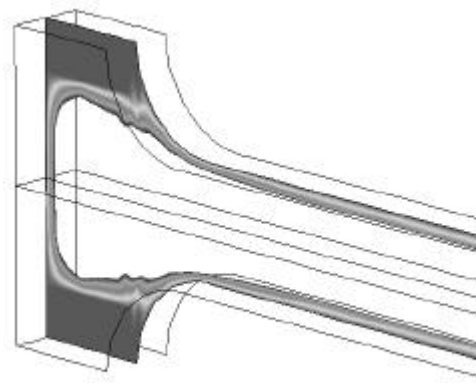


Figure 2

Reference

Haagh G.A.A.V. and Van de Vosse F. N. Simulation of three dimensional polymer mould filling processes using a pseudo-concentration method. *International Journal for Numerical Methods in Fluids*, 28:1355-1369, 1998.

Gas-Assisted Injection Moulding: In Search of Improved Heat Transfer

*R Magalhaes and G F Smith
Advanced Technology Centre, School of Engineering
Warwick University,
Coventry, CV4 7AL.
United Kingdom.*

Abstract

Non-conventional injection moulding processes have taken on major significance in plastics processing in the past few years [1,2]. Gas-assisted injection moulding of thermoplastic articles is one of many successful examples [3]. Most commonly in this process, the mould cavity is partially filled with polymer melt followed by injection of an inert gas (usually nitrogen) into the core of the molten polymer. For nearly a decade, numerical models based on a Hele-Shaw type flow have been developed to describe polymer melt flow in thin cavities during conventional injection moulding. These models are based on the so-called $\frac{1}{2}D$ approach [4,5].

Residual wall thickness of *iPP* rod-like gas injection mouldings was experimentally measured and results were compared with commercial software predictions. The usefulness of actual simulation codes is questionable, pointing the urgent need for 3-dimensional simulation codes. Furthermore, accurate prediction of the residual wall thickness is of key relevance for accurate heat transfer analysis. Heat transfer in gas-assisted injection moulded articles has been scarcely addressed in the past [6,7]. Some gas-assisted techniques for enhanced heat transfer will be presented. These techniques are being developed at Warwick and are based on gas manipulation. Cavity melt temperature profiles were recorded and modelling of one-dimensional transient heat transfer is being carried out. These aim at the validation of the proposed gas-assisted cooling techniques.

References:

1. Shaw, S. Gas-Assisted Injection Moulding: A Technology Overview. *Journal of Injection Molding Technology*, SPE, June 1997, Vol.1, No.2, p. 96-103.
2. Rush, K. C. Gas-Assisted Injection Molding – The New Age of Plastic Molding Technology. ANTEC 89, SPE, p. 1014-1018.
3. Moore, S. Gas-Assisted Injection is Taking on Tougher Challenges. *Modern Plast. Magazine*, August 1994, Vol.71, No.8, p. 52-56.
4. Potent, H., Hansen, M. *International Polymer Processing*. 1993, Vol.8, p. 345.
5. Turng, L. *Adv. Polym. Techn.* 1995, Vol.14, p. 1.
6. Yang, S. Y., Chu, P. T. Void Shape in Gas-Channel Ribs in Gas-Assisted Injection-Molded Plates. *Advances in Polymer Technology*, 1999, Vol.18, No.1, p. 11-17.
7. Gao, D. M., Nguyen, K. T., Garcia-Rejon, A., Salloum, G. *Numericam Modelling of the Mould Filling Stage in Gas-Assisted Injection Moulding*. Intern. Polymer Processing XII, Hanser Publishers, 1997, Vol.3, p. 267-277.

Finite element prediction of glass fibre orientation distributions for injection moulding of simple and complex geometry products

*S.L. Bubb, R.A. Duckett & P.J. Hine, IRC in Polymer Science & Technology, University of Leeds, LS2 9JT;
B.R. Whiteside & P.D. Coates, IRC in Polymer Science & Technology, University of Bradford BD7 1DP*

The use of injection-moulded glass-fibre reinforced thermoplastics for load-bearing applications is ever increasing. However, the use of reinforced composites poses a problem during the design of the part, because these materials cannot be assumed to possess isotropic mechanical properties. The stiffness and strength of the material are determined by the orientation of the reinforcing fibres, which in turn is dependent on the manner in which the polymer melt fills the mould. This requires that, during the design of a new product, the processing details must be taken into account so the fibre orientation and resulting mechanical behaviour of the part can be confidently predicted.

Commercial software is available which can predict both the flow of polymer and resulting fibre orientation during the injection moulding process. However, in order to reduce the computational demands required by these complex FE-based algorithms, a product is modelled using two-dimensional elements and the generalised Hele-Shaw approximation, which assumes a cavity to be thin and flat and is thus well suited to typical injection moulding geometries. Unfortunately, the model can only predict in-plane velocities, so errors can occur in regions containing out of plane flows, such as rib intersections or thick sections, which cannot be accurately modelled in 2-d.

In this study, two components with different levels of complexity were chosen for comparison of the measured fibre orientation and subsequent mechanical properties with those predicted by a commercial injection-moulding software package (Moldflow Rel. 9.5).

The first component considered was a simple tensile test component, figure 1, which was made using fully instrumented injection moulding facilities at the University of Bradford. The fibre orientation was measured throughout the component using an advanced image analysis system developed at the University of Leeds. Mechanical tests were performed on the specimen for comparison with property predictions from both theoretical models and Moldflow stress analysis.

The second component studied, figure 2, was a prototype automotive clutch pedal that possessed a more complex structure. The geometry of the pedal can be simplified to a number of connecting planar surfaces, enabling it to be modelled using the software. The complexity of the pedal required key regions to be chosen for fibre orientation analysis. Unlike the tensile bar there is no simple way to measure the mechanical properties of the component.

The fibre orientation results clearly show the difference in capabilities of Moldflow for the two components. For the simple tensile bar there is good agreement between Moldflow and the orientation measurements throughout the component, and a corresponding agreement between the modelled and measured mechanical properties. The results obtained for the clutch pedal showed a general agreement between measured and modelled orientations, but the software was shown to be less accurate in areas containing 3-dimensional flows. A good solution in these regions requires a full 3-dimensional simulation.

There are other components that cannot be described by a midplane model, due to their structure being fully three-dimensional, for example a typical gear wheel. The development of commercial software for three dimensional fibre orientation prediction is not yet feasible, with the main limitation being the amount of computing power required by current approaches. For this kind of component the measurement of fibre orientation is therefore very important.



Figure 1



Figure 2

Experimental Validation Of Numerical Simulations Of The Kneading Disc Section In A Model Twin Screw Extruder

Shaffiq A. Jaffer, Victor L. Bravo¹, Philip E. Wood, Andrew N. Hrymak*, Department of Chemical Engineering
McMaster University, Hamilton, Ontario, Canada, L8S 4L7
and Joseph D. Wright, Paprican, Pointe Claire, Quebec, Canada, H9R 3J9

Abstract

A comparison of the results of a 3D model for the simulation of flow in the kneading disc region of a fully intermeshing twin screw extruder model has been done against particle image velocimetry (PIV) experimental data. Experimental results using a geometry with an extended first and last kneading disc to capture the simplified inlet and outlet boundary conditions, are in good qualitative agreement for low flow rates. The flow was an idealized fully filled viscous Newtonian oil. The results showed good agreement at flow rates less than 5 mL/s and rotation speeds of 60 rpm, while above that there was poor agreement. These results highlight the importance of the use of appropriate boundary conditions for the accurate prediction of the flow field. The flow field within the kneading discs with forward conveying elements placed before and after the kneading discs was also measured. For a flow rate of 8.5 mL/s and 60 rpm, results showed good agreement when conveying elements were deployed before and after the kneading blocks whereas for lower flow rates there was poor agreement.

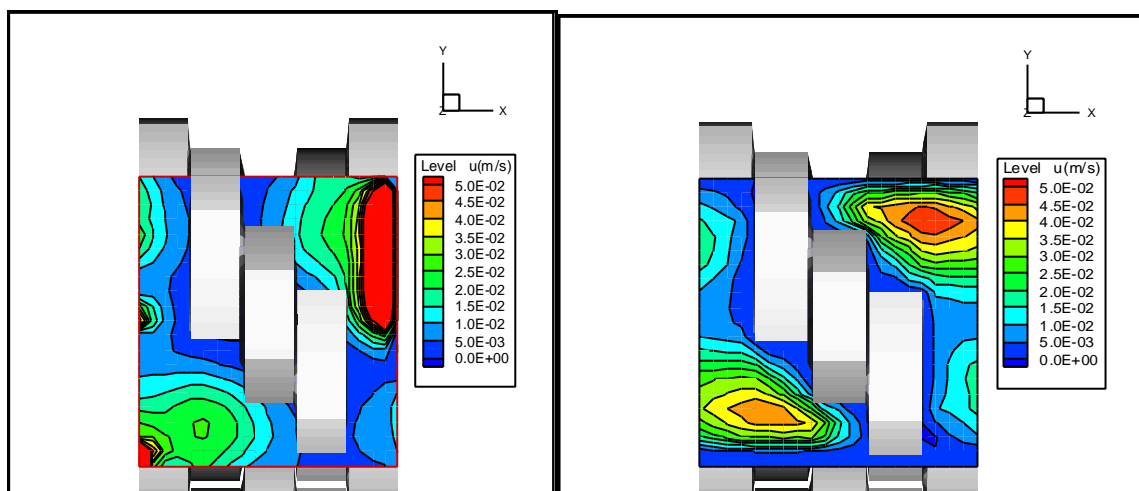


Figure. Contours of the x-component of velocity. Left screw, 60 rpm, 8.5 mL/s. Conveying elements deployed before and after the kneading blocks. a) Experiment b) Simulation.

References

- V.L. Bravo, A.N. Hrymak and J.D Wright, "Numerical simulation of pressure and velocity profiles in mixing elements of a co-rotating twin screw extruder", in press, Poly. Eng. Sci.
- S. Jaffer, V.L. Bravo, P.E. Wood, A.N. Hrymak, and J.D. Wright, "Experimental validation of numerical simulations of the kneading disc section in a twin screw extruder", accepted Poly. Eng. Sci.

A role of the extensional viscosity in extrusion process

Jiri Vlcek – Compuplast International, Inc. Nerudova 158, 76001 Zlin, Czech Republic
Tom Dobbie – Rosand Precision, Balds Lane, Lye, Stourbridge, West Midlands, England, DY9 8SH

The material property called extensional viscosity characterizes the material resistance against stretching. It has been mentioned as a material characteristic for a long time and its shape was usually calculated from visco-elastic models. Only in the last decade, there were found some ways, how to measure it. This opened a possibility to use this material property in modeling real flow situation from extrusion processes. This paper demonstrates the role of the extensional viscosity in some flow situations that we were facing in our work.

The first task is how to incorporate the extensional viscosity into the simulation. In paper [1], the authors have presented a relatively simple model for a reasonable fitting of both shear and extensional viscosity data. The role of the extensional viscosity is simulated by using White-Metzner model with a special form of the viscosity function and the relaxation time.

$$\vec{T} + \mathbf{I}(\mathbb{I}_d) \frac{D\vec{T}}{Dt} = \mathbf{h}(\mathbb{I}_d) \vec{d}$$

where \mathbf{T} is the stress tensor, $\mathbf{I}(\mathbb{I}_d)$ is the relaxation time, $\mathbf{h}(\mathbb{I}_d)$ is the viscosity, D/Dt is the time derivative, \vec{d} is the rate of deformation tensor and \mathbb{I}_d is the second invariant of this tensor.

The relaxation time has a form

$$\mathbf{I}(\mathbb{I}_d) = \frac{\mathbf{I}_0}{1 + K_2 \mathbb{I}_d}$$

For $\mathbf{I}_0 / K_2 > \sqrt{3} / 2$, this relaxation time dependence ensures that the model never diverges for an extensional flow. The viscosity $\mathbf{h}(\mathbb{I}_d)$ is given by any viscosity model predicting a plateau for the zero viscosity. Such models are for example **Carreau** or **Cross** model /1/. It was shown in /1/ that this model describes reasonably well the material behavior for extensional flows but heavily underestimates the development of the first normal stress difference in the shear flow. The reason for this is that the Weissenberg number reaches for high shear rates a constant value. Because of this feature, the stresses can be incorporated into the equations describing the flow and the stability of the numerical solution is higher than in case of models generating high Weissenberg numbers.

The role of the extensional viscosity will be presented for three flow situations. The first one is a flow inside a dual capillary. It will be shown that the simulation can provide a pressure lost generated by flow in sudden contraction inside both reservoirs that is in correspondence with the measurement. There is also shown a comparison with a simulation where the extensional viscosity is neglected.

The second flow situation is a distribution on a simple flat die. The die was design in a way that the transitions from both a deep feeding channel into the gap above the restrictor and the relaxation chamber into the gap between lips are sudden contractions /2/. Also in this case, it is shown that it is necessary to incorporate the extensional viscosity into simulation, otherwise the results do not correspond to the observation.

The last flow situation is from coextrusion /3/. It will be shown that the extensional viscosity can play an important role in conditions for occurring long wave interfacial instabilities.

Literature:

- 1) Barnes H.A., Roberts G.P.: *A simple empirical model describing the steady-shear and extensional viscosities of polymer melts*, Journal of Non-Newtonian Fluid Mechanics, 44 (1992), 113-126
- 2) Mailvaganam G.N.: *An experimental study of polymer flow in flat dies*, Master thesis, McMaster University, Hamilton, Ontario, Canada, 1990.
- 3) Zatloukal M., Tzoganakis C., Vlcek J.: *Predicting the onset of interfacial instabilities in coextrusion flows*, TAPPI 7th European PLC symposium, Prague 1999.

Balance, Optimize and Design: A Comprehensive Computer Model for Extrusion Die Design

Th. Marchal, Y. Rubin, J.M. Marchal & A. Goublomme -- Polyflow s.a.

Extrusion is the process used to manufacture products in the form of continuous lengths with a uniform cross section. The function of the die is to convert the cylindrical flow from the extruder and shape the polymer into the required, sometimes quite intricate, cross section. The design of such dies is often quite complex.

Traditionally, dies have been designed by an expensive trial and error procedure, with multiple trials and modifications. The main reason for this lengthy design process is that the flow patterns inside the dies and their sensitivity to changes are not known.

Using 3D numerical analysis and accurate material properties, it is now feasible to obtain the flow patterns inside dies used, for instance, for the extrusion of window profiles, automotive rubber seals, biomedical tubing, etc. to design better dies. 3D flow patterns in the die, die swell and thermal effects can be taken into account to provide the die designer with the most valuable recommendations to balance the polymer flow out of the die and design a better die lip shape for the required profile [1]. As a result, the number of trial and error is significantly reduced together with the time to market and the actual die design cost [2, 3, 4, 5].

An optimization functionality has recently been incorporated in POLYFLOW[®] and coupled to the flow analysis to allow the parametric modification of materials properties, operating conditions and/or geometrical control points. Using design sensitivity analysis, this enables the design of die shapes and extrusion conditions such that the best possible flow uniformity at the die exit is obtained. Typical degrees of freedom include the position of control points for complex sections, the length of adequate regions in PVC preforms, and position of mandrels in medical (catheters) applications. It is shown that the automatic optimization scheme is able to optimize dies more effectively and faster than the manual 'trial and error' approach.

References:

- [1] Polyflow s.a., POLYFLOW version 3.7 Users Manual, Louvain-la-Neuve, Belgium (1999).
- [2] Reese, C., Marchal, T. & Marchal, J-M., *Use of die modeling to improve the manufacturing process for extruded silicone rubber*, Proc. of the ANTEC'94 conference, ed. Society of Plastics Engineers, Brookfield CT, (1994), vol. I, 94-99.
- [3] Andrejewski, D., *Polyflow: a treatise on inverse die/mandrel design for high consistency silicone elastomer*, Proc. of the ANTEC'97 conference, ed. Society of Plastics Engineers, Brookfield CT, (1997), vol. I, 308-314
- [4] Rubin, Y., Marchal, T. & Röthemeyer, F., *Die design improvements through numerical simulation for the extrusion of EPDM compounds*, Proc. of the IRC-97 Conference, Nuremberg, (1997).
- [5] Rubin, Y. & Roy, P., *Computer assisted design of extrusion dies for multilumen medical tubes*, Proc. of the *COMPPRO paper 9*

The Calibration Process in PVC Profile Production: Experimental Trials and Computer Simulation

Ulrich Conrad¹, John F T Pittman¹ and Ivo Szarvasy²

¹PolySim Research Centre, University of Wales Swansea, SA2 8PP, UK

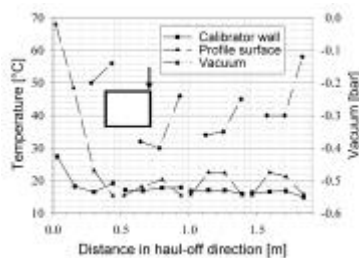
²Kömmerling Kunststoffwerke GmbH, Pirmasens, Germany

Calibration in uPVC profile production refers to the process immediately downstream of the extrusion die, where the profile is cooled and solidified, and where its outer dimensions are fixed. A calibrator consists essentially of a water-cooled metal block with a closely fitting and appropriately shaped prismatic channel through which the profile passes. Slots in the calibrator connect this inner channel to vacuum, which stabilises it against the channel walls. Up to eight calibrators may be used in succession and these may be run wet or dry. To allow for shrinkage on cooling the profile channel dimensions in successive calibrators are reduced slightly, and cooling is usually completed using downstream water baths, either with or without vacuum. Parameters of the calibration exert an important influence on the properties of the finished profile, and it is the calibration process that usually sets the limit to the line speed that can be used. Requirements for successful calibration include the following:

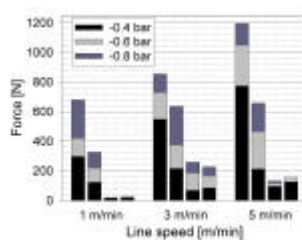
- an adequate but not excessive length of the calibration line, to cool and stabilise the profile;
- proper design of the calibrator channels to allow for shrinkage and geometry change with cooling, whilst maintaining good thermal contact with the profile, avoiding excessive frictional drag, and allowing for elastic recoil to the final profile cross section at the exit of the last calibrator;
- choice of appropriate processing conditions including extrusion temperature, line speed, and applied vacuum

The development of new calibration tools for complex PVC window profiles is traditionally a very time-consuming process, involving repeated trials and modification. The complex, multi-physics nature of the process has hitherto prevented the use of reliable calculation methods in design, and necessitated expensive trial and error methods

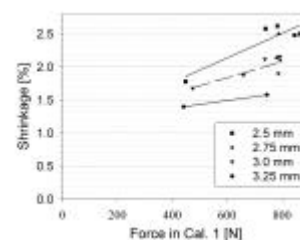
The presentation will give an overview of a project that combines experimental trials with the development on finite element simulations. Experimental work includes trials on a highly instrumented line, providing probably the most comprehensive sets of processing data available, together with tests on the finished profiles. A finite element simulation of profile cooling includes heat transfer by convection and radiation with and within the air cavities inside the profiles, transient conduction in the PVC, and convective heat transfer from the outer surface. A thermo-viscoelastic model for stress relaxation, thermal stress development, shrinkage and distortion is coupled with the cooling analysis, and is supported by rheological and mechanical characterisation of the PVC. Sample experimental and simulation results will be presented.



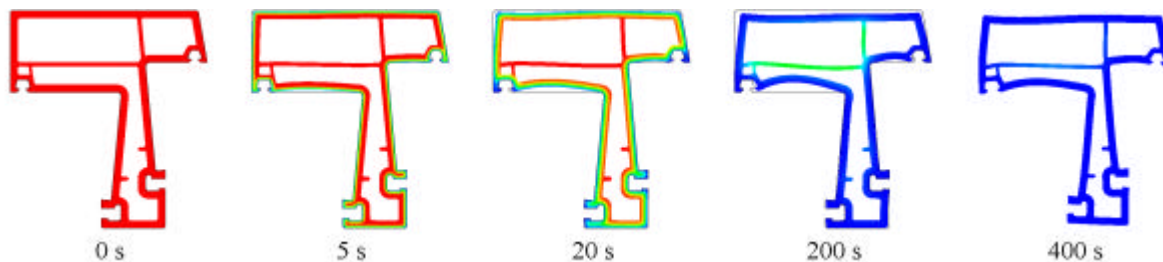
An example of temperature and vacuum data recorded on a line with four calibrators.



Forces on each calibrator (1 to 4, upstream – downstream) as a function of line speed and applied vacuum.



Correlation for profile shrinkage. Line speed 4m/min, die exit 2.5mm. Results for various profile wall thicknesses.



Modelling of visco-elastic free surface flow in a rubber mixer

L.Hou, P.K. Freakley, V.Nassehi

Rubber Process Engineering Centre

University of Loughborough

Batch internal mixing of rubber involves visco-elastic free surface flows in a complex geometric domain. Wall slip is also known to occur and exert a substantial influence on the accessible stress for mixing and on flow distribution. A combined scheme for the Cauchy equation of motion and the Phan-Thien/Tanner (P-T/T) constitutive model is developed. This scheme is based on the finite element solution of the governing equations of stress induced visco-elastic free surface flow in a partially filled rubber mixer. The initial velocity field is found solving the Navier/Stokes equations. The initial velocity field is used to calculate the stresses via P-T/T equation. The stress values are in turn inserted into the Cauchy equation of motion which in conjunction with the equation of continuity yields the updated velocity field. After the initial step the scheme proceeds with decoupled iterative solution of the Cauchy and P-T/T equations. We use the Arbitrary Lagrange Euler (ALE) method to track the free surface boundary within the flow domain. The developed scheme is capable of simulating wall slip conditions and can also take into account the compressibility of air pockets within the rubber/carbon compound under high pressures. To make the scheme industrially relevant we are working on methods to increase the speed of computations.

Coefficient of static and dynamic friction measurements for plastics against thermoforming plug materials at elevated temperatures

P Collins, J Lappin, E Harkin-Jones, P Martin,

Queens University Belfast

The static and dynamic coefficients of friction are measured for thermoplastics such as polystyrene, polypropylene and polyethylene against plug materials used in the plug assisted thermoforming process. Measurements are made using a combination of an oven and a friction tester. The data measured is required for a finite element model of the plug assisted thermoforming process.

FEA OF SOLID POLYMER GEOGRID MANUFACTURE USING A SLIPLINK CONSTITUTIVE MODEL

*P Caton Rose, J Sweeney, P D Coates
Department of Mechanical & Medical Engineering,
IRC in Polymer Science & Technology,
University of Bradford, Bradford BD7 1DP UK*

Applying the elastic constitutive model of equation (1) within a finite element analysis, predictions can be made of biaxial deformation of solid phase polymer products such as Tensar Geogrids.

$$\mathbf{s}_{ii} = N_c \mathbf{I}_i^2 + N_s \mathbf{I}_i b'(\mathbf{I}_i) - p \quad (1)$$

N_c and N_s are proportional to the number of crosslinks and sliplinks, per unit volume, respectively for a chain network as derived by Sweeney and Ward (1) from the ball et al hyperelastic constitutive theory (2).

Predictions are based on the analysis of repeat units within a netlike structure, as shown in Figure I. Validation of the output from finite element analysis is based on the localised strain measures as shown in figure II for a primary draw ratio of 6 and a secondary draw ratio of 2.

Data series 7 to 8 relates to the central portion of the gauge width whilst 1 to 2 relates to the central portion of the repeat unit, or junction point. From Figure II it is clear that the localised strain response of the main gauge width is predicted well, whilst the material within the junction point draws to a greater extent within the experimental sample. This is due to the lack of strain rate dependence within the constitutive model.

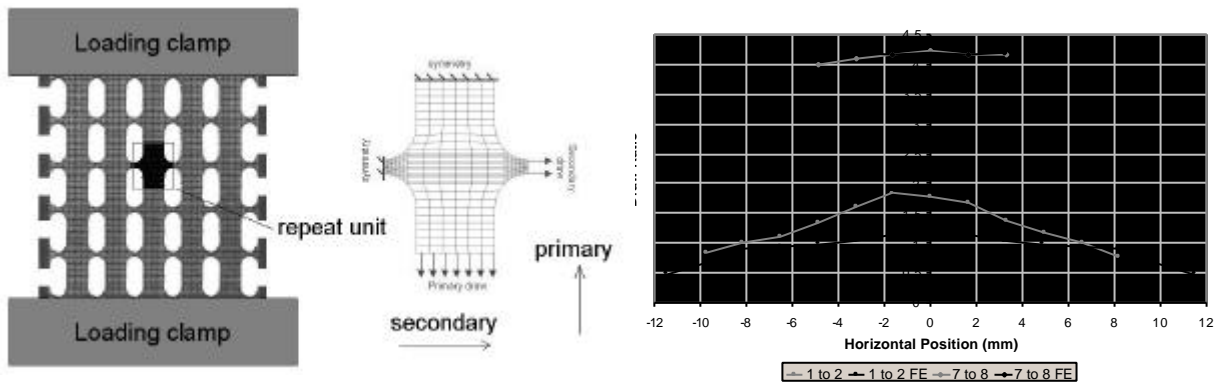


Figure I: Repeat unit within a Geogrid structure

Figure II: Strain response of a Geogrid repeat unit.

REFERENCES

- 1 Sweeney, J. and Ward, I.M., Journal of Mechanics and Physics of Solids (1996), Vol. 44, No. 7
- 2 Ball, R.C., Doi, M., Edwards, S.F. and Warner, M., POLYMER (1981) Vol. 22

Computer Aided Design of Preforms for Injection Stretch Blow Moulding

G Menary^{}, CG Armstrong^{*} and JP McEvoy⁺*

^{}The Queen's University of Belfast, ⁺Boxmore Plastics Ltd*

Simulations of the injection stretch blow moulding process have been performed for three 3D bottles using the Finite Element package ABAQUS/Standard. These bottles have volumes of 330ml, 1litre and 2 litre, which represents the typical range of PET bottles that are currently being manufactured in Boxmore Plastics. The objective is to validate the simulation over the range of stretch ratios that are found from preform to bottle in each case.

A new technique has been developed for simulating 3D bottles. This involves running the analysis in 2D until the material has reached the petaloid base, which is 3D. At this point the analysis is stopped, the boundary conditions are modified, the 3D base is added and the analysis continues in 3D. This has significantly reduced the computational time required to run a 3D simulation of a bottle.

In order to optimize the design of preforms/bottles the output of thickness distribution from the simulation is not enough. The designer is required to know the bottle shelf life and how it will respond to internal pressure and axial top load. There are a number of material properties that influence these phenomena. These include crystallinity, modulus, stretch ratio and orientation. These values have been measured by taking samples from a 2-litre bottle, but the eventual aim is to predict them during the simulation of the injection stretch blow moulding process. The experimental values for the crystallinity have been used to calculate the permeability of the blown container. These values for permeability have been input into a FORTRAN program that is used to predict the shelf life of the blown container. The results have been compared with experimental values for the bottles described above.