**Proc. XIVth Int. Congr. on Rheology**
*Edited by:*
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August 22-27, 2004
Seoul, Korea

# Time Dependency of Viscosity in the Flow Simulations

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## ABSTRACT

The CAE simulation is not accurate enough in contemporary high speed manufacturing processes. In injection moulding the filling of a mould cavity can happen in fraction of a second. The viscosity changes at different shear rates are based on molecular orientation and on amount of entanglements. The change of these statistical elements needs some finite time having great effect on flow simulations, beside of temperature, pressure and other known variables.
The earlier generated linear relation [1-2] between polymer structure such as MWD and properties. such as relaxation and viscosity functions has been developed further. Viscosity as a function of time, called shortly *transition viscosity,* can be modeled similar way.
These simulated material properties are generated by DataPower software package giving effective synchronized on-line service to CAE/CAD/CFD simulation software. A simulation Client program makes viscosity data requests for all elements of grid, and DataPower Server gives responses in milliseconds. Some on-line simulations and results from modelling capillary rheometer measurement and manufacturing of small injection moulded parts are presented.

## INTRODUCTION

Polymer has a wide range of sudden shear rate changes during extrusion and injection moulding processes. *Transition viscosity* is true effective viscosity including shear history and its value approaches the value of steady state viscosity during time. Viscosity varies strongly during deformations not only as function of shear rate but also time or $\eta(\dot{\gamma},t)$.
These relaxation, retardation and ramp tests have been studied by simple principal cases in rheology, but not applied for practical viscosity.
Many software, models and meshing methods are available in the CAE programs, but time-dependent viscoelastic data including shear history are lacking. DataPower Server is a stand-alone program sending synchronised viscoelastic data to any client program in the same or remote PCs by wide used TCP/IP protocols.
In the paper software and system arrangement is explained at first (see Fig 1). The used formulas are shown before material data file generation procedure and results of simulation run with CAE/CAD/CFD Clients.

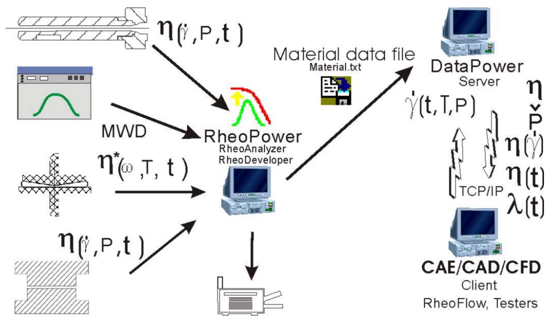


*Figure 1. RheoPower software family delivers material data files to separate DataPower Server. This can be located in same computer with CAE/CAD/CFD Client software or in remote mode saving computation resources. Client program gets flow and rate synchronized viscoelastic data by TCP/IP protocol in the ready use mode. DataPower can serve also CAE/CAD/CDF programs on Linux/Unix platforms.*

## USED SOFTWARE AND SYSTEM

RheoPower software family was originally developed for detecting Molecular Weight Distribution MWD from viscoelastic measurements.[1-2] Oscillating rheometer in frequency sweep mode with small strains is the only measurement device, which was found to produce enough accurate data for our numerical analyses. At first, linear relation between complex viscosity η* and MWD by RheoAnalyzer is needed to set up. An alternative is to use another program of RheoPower software family, called RheoDeveloper. RheoAnalyzer can detect directly MWD from viscosity flow curve. RheoDeveloper starts from MWD and simulates the flow properties. These programs do not only develop linear relation between measured viscosity and MWD, but also model wide fit for viscosity, relaxation spectrum, modulus and dynamic elastic G' and viscous G" moduli.

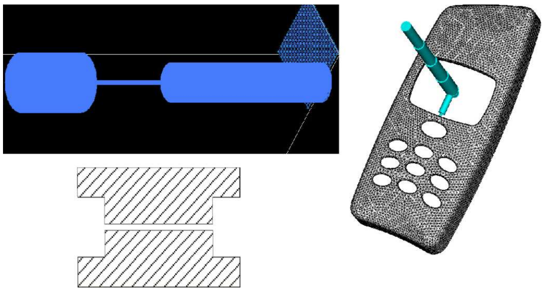

*Figure 2. Used capillary by Simcon's cmv6 simulation software (left top) and geometry used byRheoFlow (left bottom). Moulded part designed by Perlos (right) used for laboratory simulation runs.*

Figure 2 shows the used mould for simulation (front cover of cellular phone) and capillaries used for simulation of measurements. The used formula for transient viscosity η is written in short form for capillary as a function of shear rate and *Polymer Structure Function* P having values in the range 0<P<1 at different rates Z.

$$\eta = \eta_0 \, Z^{-P} \sim K \, |\dot{\gamma}|^{n-1} \qquad (1)$$

Polymer structure function is a sum of elastic and viscous integral components and shear history as explained more elsewhere.[1-2] The RheoPower principle uses only two constants, which set relation between molecular structure and flow

$$Z = \left(\frac{Mf}{M}\right)^{H} \qquad (2)$$

Variable Z is normalised or non-dimensional shear rate $|\dot{\gamma}|$ or frequency, and constant Mf is polymer structure value for molecular weight M. Polymer flow function H sets relation between flow structure and rate or frequency. Polymer structure values converted to percent values P% are comparable at reference temperature.

## EXPERIMENTAL

For this study we use BASF LDPE H1840, a derivative of well-known IUPAC A. The influence of pressure is included by Barus formula and temperature rise is attained in capillary due to friction. For capillary (L/D=20) we get simulation results shown in Figure 3, which are at same level as measured by Laun.[3]

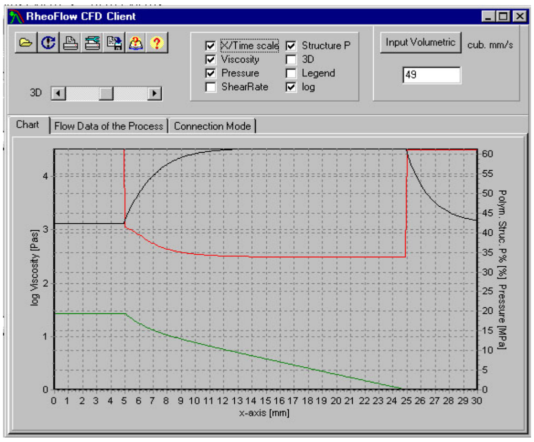


*Figure 3. Simulation of capillary flow by RheoFlow program at constant melt temperature for clarity. Blue curve is shear rate and red one is transient viscosity in log scale (left) as a function of displacement. Green curve is pressure loss and black shows orientation degree in percent by P%.*

We can collect data of measurements and simulations at different frequency and rate shown in Figure 4. Now the important point is that only Mf and H values are different for oscillating frequency and capillary shear rate in RheoPower.

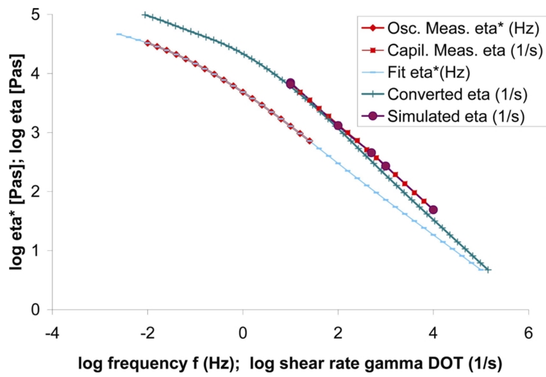


*Figure 4. Oscillating and capillary measurements are collected and marked by red squares. Simulations are marked by lines.*

The Client/Server idea can be used by programs within a single computer or in a network. DataPower Server shown in Figure 5 gives requested data response in few milliseconds.

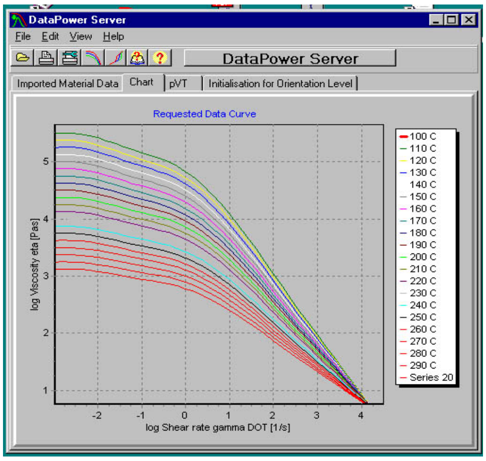


*Figure 5. DataPower Server shows steady state viscosity family at different temperatures.*

Used CAE Client for these simulations was cmv6 development software version delivered by Simcon kunststofftechnische Software GmbH. This software stores for every grid elements the shear history and orientation by old P% values. Before doing new data request, cmv6 computes for all elements time step t, new pressure P, temperature T and imposed shear rate $\dot{\gamma}$. DataPower gives back to Client for every element new transition viscosity and new P% value to store in memory. Summary the data transfers for elements are done via small open source DLL program as follows:

Client: (t,P,T, $\dot{\gamma}$, P%) => Server: (P%, η)

## RESULT AND DISCUSSION

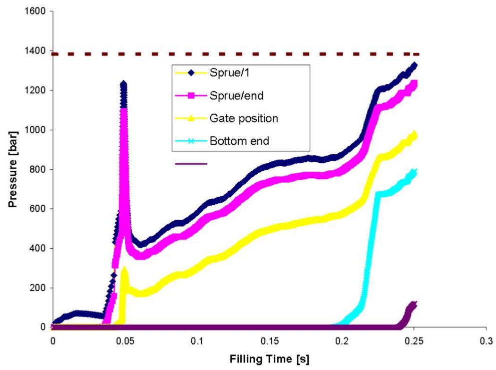


*Figure 6. Simulated pressure rise in front cellular cover at some points. Results are close to measured values.*

Pressure simulation for thin cellular front cover during filling phase can be seen in Figure 6.

Since shear history, orientation and polymer structure state are very essential for simulation, which also forecasts end properties as warpage, we look P% values in capillary shown in Fig 7.

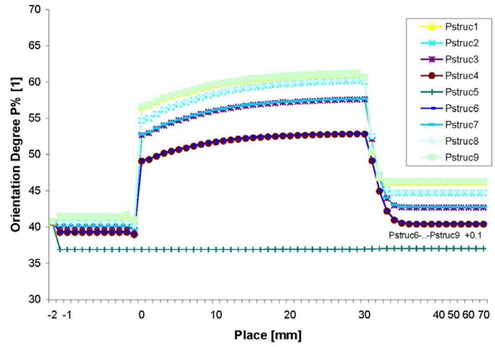


*Figure 7. P% values show in a capillary orientation degree of layers at different place.*

Orientation for cellular cover during filling phase at some selected point is shown in Figure 8. The higher level are P% values the higher is the orientation.

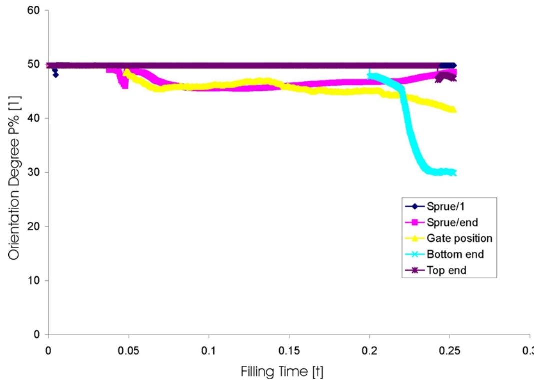


*Figure 8. P% values in the cellular cover. The level at the end of filling is very important for quality.*

## SUMMARY

Accurate complex viscosity of oscillating rheometer added by capillary measurements can be used for generating complete analytical data. This offers chances for more accurate simulation of pressure and orientation degree, which has relation to the shrinkage and warpage of injection moulded parts.

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3. H. M. Laun, Rheol Acta, **42**, 4 (2003).