

It is some years since we last looked at Compuplast's suite of software for extrusion modelling. Clive Maier finds that a lot has changed.

Screwing down extrusion

INJECTION moulding may get most of the attention but it is extrusion that shifts the most material – and by a long way. The very nature of the process – continuous, not batch – lends itself to bulk output. All told, extrusion accounts for almost 60 per cent of plastics consumption. The bulk of that is film and sheet. Injection moulding limps in with about 25 per cent, ahead of blow moulding and thermoforming. And when you remember that much of blow moulding uses extruded parisons, and thermoforming is conducted on extruded sheets, extrusion turns out to be even more influential.

The big markets for plastics are packaging and construction, and extrusion accounts for the major share of these in the form of film, sheet, pipe and profile. Once again, star quality intervenes to cloud our perceptions. We hear a great deal about automotive markets for plastics but the actual volume is about the same as the share for agricultural and horticultural applications – and almost all of those are extruded too.

So extrusion is important. It is also sophisticated. Many packaging films are complex multi-layer co-extrusions. Some profiles such as weather seals are co-extrusions too. Products like window profiles have to be precise in size and shape to do the job. Cable coating effectively involves inserts. And gauge is so important. When you are producing film in volume, small variations in gauge make the difference between profit and loss.

Crucial to all this is the matter of die design and what goes on upstream in the extruder. The single-screw extruder was probably the first component of plastics processing to be modelled mathematically, but die design has been just as much a black art for extruders as moulds were for injection moulders. Because extrusion is essentially a bulk process, the ratio of tooling to product is much lower than it is *The module menu.*

for moulding so the time and money sapping effects of trial and error may have been less obvious. But the imperatives are just the same. New products must come to market quickly, margins are being squeezed, offshore competition looms. It is time for black arts and experimentation to give way to science and rational design, the goal being to get the product as nearly right as possible first time. All in all, a suitable case for simulation.

Compuplast's Virtual Extrusion Laboratory is a suite of software modules – CAE tools – for designing and optimising virtually all extrusion processes. It is the result of many years of development and industrial use, and is effectively in its fourth generation.

The code had its origins in academic work at McMaster University in Ontario and was eventually commercialised as DOS programs in the early '90s by Polydynamics. The third generation came when Compuplast International, one of the first private enterprises to be set up in the Czech Republic, completely re-engineered the programs for Microsoft Windows. Now users had pictures as well as numbers to work with. Suddenly it was much easier to understand and use the results; the essential step in turning a niche specialism into an industrial tool.

Later in the '90s Compuplast and Polydynamics agreed to go their separate ways. Since then Compuplast, led by Dr Jiří (George) Vlček, has been solely responsible for the content, look and feel, marketing and support of the software. George Vlček by the way, was instrumental in creating those early DOS versions while a research assistant at McMaster.

Compuplast marketed the third generation Windows programs as its Flow 2000 suite and the principles proven there remain

the foundation of its successor, the Virtual Extrusion Laboratory. There have been refinements and additions of course, but what makes VEL a fourth generation product is the focus on extrusion solutions rather than program features. If they are going to be used to the full in industry, computer simulations can't be the preserve of a few initiates.

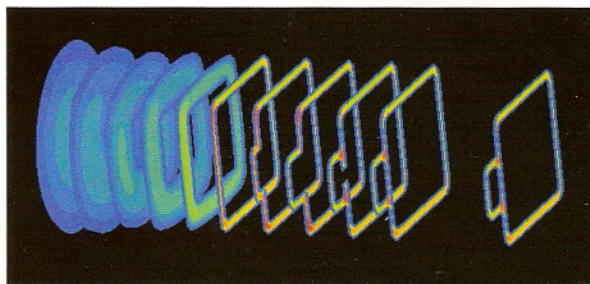
The essentials

The Virtual Extrusion Laboratory is a suite of modular process-oriented computer simulation tools for designing and optimising virtually any extrusion process or single-screw extruder. The object is to replace trial and error and best estimate methods by rational design on scientific principles. The justification is that being nearly right first time saves a great deal of time and money, and makes a company more competitive.

The modules cover sheet, blown film, cast film, coating, profile, pipe, cable coating, and extrusion blow moulding. Further modules deal with the extrusion of rubbers and thermoplastic elastomers, and with medical applications such as multi-lumen tubing. A general 'Extrusion Experts' module covers the whole gamut and is suitable for researchers, consultants, educators and equipment manufacturers.

www.flemingptc.co.uk

Factfinder 146



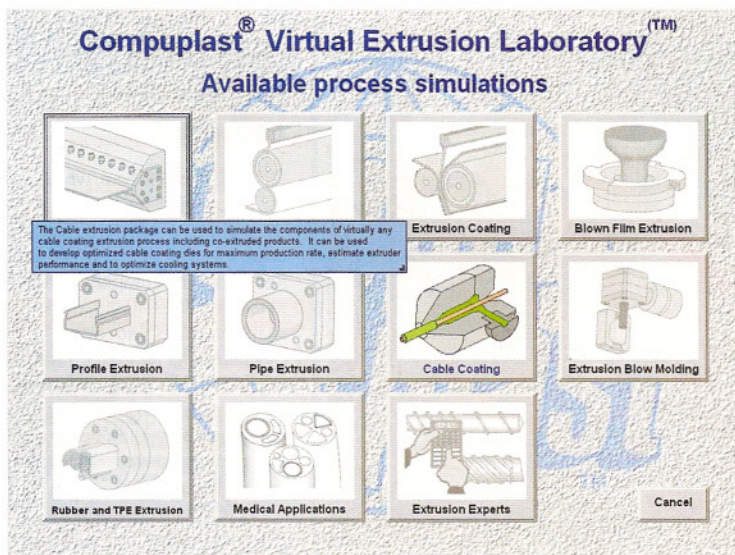
2D sections define a profile die.

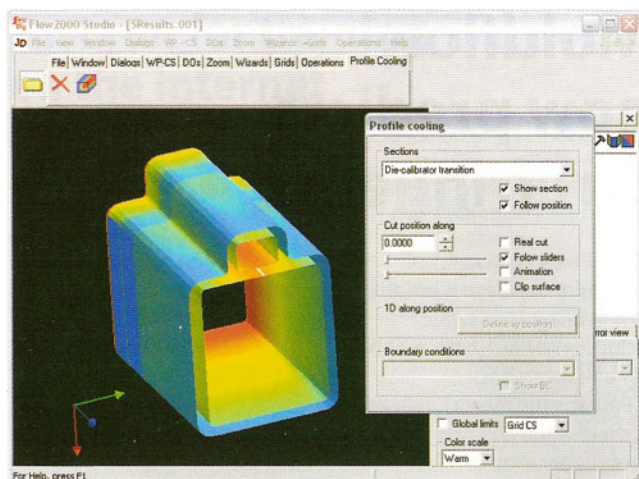
They have to be immediately accessible – and immediately useful – to any normally computer-literate extrusion engineer. That is why the software functions in VEL have been packaged into modules that are specific to extrusion processes.

There are modules for sheet, blown film, cast film, coating, profile, pipe, cable coating, extrusion blow moulding, rubber and thermoplastic elastomers, and medical applications. Each module contains all the capabilities needed to deal with the process and there is a good deal of code and functionality that is shared between them. The point is that the user does not have to worry about making the right selection from an array of simulation tools. The right ones for the particular process are laid out and ready for use within a user interface focused on that process.

The first thing you see on running Virtual Extrusion Laboratory is a graphical menu of these process modules. Because VEL is modular software, you don't have to buy them all. Those you have not licensed will still be present in the menu but greyed out. A click on any one takes you to the chosen process module.

Let's take profile extrusion. This module can be used to design and optimise virtually any extruded profile, including co-extruded types. The software can optimise the die for maximum output, estimate extruder performance, and optimise the calibration and cooling systems. In optimising the design, the program takes into account problems like extrudate swell, melt fracture and flow balancing through the die.





Cooling and calibrating the extrudate.

Here we come to the Compuplast philosophy of die design. The aim, of course, is to achieve an extrudate that is absolutely true on its axis and conforms in cross sectional shape and size to the specification laid down by the product designer. Most profiles consist of walls and webs of varying extent and thickness, united by curves, angles and corners. A simple plate die would result in entirely different flow rates through these contrasting profile regions and once that happens, an accurate extrudate is out of the question. So it is a major design objective to create a die in which the proportion of the total extrusion flow rate in any one of these regions is the same as the proportion its area holds to the total area of the final profile. If this is done, it means that flow in each region is perpendicular to its profile and there are no cross-flows. Compuplast refers to this approach as the cross-flow minimisation method, or CFMM.

This leads to a surprising conclusion. The transition of the flow channel from extruder barrel to die exit involves thick regions that would seem to demand analysis in 3D. The Virtual Extrusion Laboratory includes solutions in 1D, 2D and 3D but Compuplast finds that some 90 per cent of all cases can be solved in 2D, and reserves 3D for those cases where significant cross-flows take place. Indeed, it is a fundamental assumption of the 2D profile die software that cross-flow is zero.

So a profile die in VEL is approximated as a series of 2D profiles that adequately define the transition from barrel bore to die exit. This is effectively a digital concept in which the analogue shape of the transition is represented by a series of steps. If the steps are very fine, the approximation is very close but computing time goes up. As always, there is a law of diminishing returns in CAE and the idea is to stop computing when further work adds little to the accuracy. In practice, the steps are often those defined by the plates that make up the die.

A design study in the Virtual Extrusion Laboratory is known as a project in which a geometry is linked with a material. The materials are held in a database and their viscosity behaviour can be defined according to the Newtonian, power law, Carreau, log-polynomial or Cross models. Temperature dependence can

be expressed by means of the exponential, Arrhenius or WLF (Williams-Landel-Ferry) models. The materials functions are accompanied by an extrusion calculator where you can make a quick assessment of the practical performance of a material by calculating flow in parallel or converging tubes and plates, in annular channels, and in the metering section of a single-screw extruder.

The geometry part of the project, of course, describes the die geometry, starting with the final desired extrudate shape. We are dealing with 2D sections,

so shapes can be defined by entering X and Y co-ordinates or nodes in a graphical geometry editor. You can also import geometries in standard DXF CAD format.

Conceptually, as we have seen, it is important to identify thick and thin regions in the final shape, where differential flow rates can be expected. The designer then defines transitional approach sections that seem likely to result in uniform flow to each region. Later this initial concept will be balanced and optimised in the software.

The next step is to create a finite element mesh. VEL meshes the 2D sections with triangular elements. The rest of the project set up takes place in a project editing window where we define the process by specifying matters such as mass flow rate (throughput) and line speed. When data entry is complete, click on the 'test' button and the system will verify whether the project has all the inputs needed for a solution.

When all is well, a click on the 'solve' button brings up the profile die solver window where you can see the solution taking place by means of progress bars and a tree-structured journal of solution information. When the solution is complete, the Virtual Extrusion Laboratory writes the results into files and opens up the profile die results viewer. Here the display of colour-contoured plots can be panned, zoomed, rotated and manipulated in all the now-unusual ways. The results sets include velocity, pressure and pressure drop, shear stresses and shear rates, and Weissenberg number. This is a dimension-less number that essentially represents melt elasticity and is therefore related to extrudate swell.

The results on this first pass will show whether the criteria for minimising cross flows have been met. If there is a large disparity then adjustments to the transitional profiles are needed, either

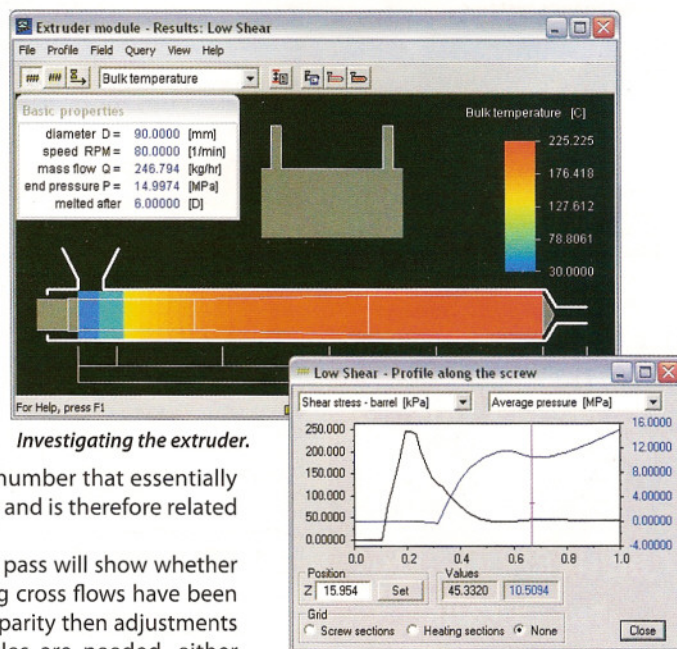
to promote or throttle flows until there is a near match between regional proportion of final area and proportion of throughput. Fine tuning to achieve a full balance can then be performed by means of an iterative procedure on a single feature such as the thickness of a given region.

So that is a look at profile design and it is representative of the general look and feel of the entire Virtual Extrusion Laboratory program suite. VEL comes complete with help files, examples and tutorials, all in the form of compiled WinHelp files. These certainly help to break the ice for the new user, especially if you have a large screen where you can view these side by side with the program.

WinHelp files are notoriously inconvenient to print, but licensed users do get a hard copy manual of the tutorials. Are these materials sufficient in themselves to get you off to a flying start? I think not. The software is not unduly daunting but a training course is worthwhile for a new user and will get you productive inside two days in the estimation of Dr Don Fleming.

Dr Fleming, a long-time VEL user himself, runs Fleming Polymer Testing & Consultancy, the new UK distributor and support service provider for Compuplast International and the Virtual Extrusion Laboratory software. The core business at Fleming Polymer Testing & Consultancy is determining the rheological characteristics of plastics by capillary rheometry. Thus the company is ideally placed to supply materials data for VEL, something that is particularly important where proprietary grades are concerned. Accurate information about elongational viscosity is also crucial for some aspects of extrusion and Fleming is currently working with Compuplast on new ways of determining extensional data at low strain rates.

A demo disc containing the entire Virtual Extrusion Laboratory suite, complete with help files, examples, tutorials and supporting papers is available from Fleming Polymer Testing & Consultancy.



Investigating the extruder.