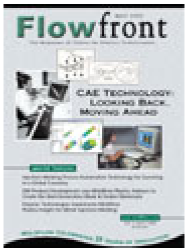

Flowfront

CAE TECHNOLOGY: LOOKING BACK, MOVING AHEAD

History of Injection Molding Simulation — the state of the technology after its first quarter century

By Marcia Swan, Moldflow Corporation

Manufacturers have been injection molding plastic parts since long before simulation technology arrived on the scene. It was apparent from early days that process variations affected part quality, but because of the complex interplay among the process physics, material properties and geometric complexity of the part and mold, successful injection molding was considered almost an art form. Experience gained through trial and error was the only means of dealing with problems encountered in the process.

During the 1970s, the use of plastics in manufacturing grew rapidly, and with it, demand for increased quality of molded parts resulted in increased interest in mathematical modeling of the injection molding process. These early efforts at simulation focused on simplistic parts and offered little practical help to engineers involved in manufacturing real products. Nevertheless, a scientific basis for simulation was established upon which we continue to build today.

Art and Science

In 1978, Moldflow introduced commercial injection molding process simulation software on a worldwide computer time-sharing system. This first computer-aided engineering (CAE) analysis enabled users to determine basic process conditions — melt temperature, mold temperature and injection time — and to balance flow in cavities and runner systems. This software required a layflat model of the part under consideration, which reduced the problem of plastic flow in a three-dimensional shape to flow in a plane. Each flow path on the layflat model could be analyzed. While this type of analysis provided useful results, it was still quite time-consuming to produce the layflat model and optimize the various flow paths.

A significant breakthrough in injection molding simulation was the introduction of finite-element analysis. This approach offered one obvious advantage over the layflat analysis: the model of the part used for analysis resembled the actual part geometry, and analysis results could be displayed on that part model. In 1983, Moldflow introduced a finite-element filling analysis program that found ready acceptance in the market, but generating the midplane model of the part still required a great deal of skill, knowledge and time on the part of the user.

Since the early 1980s, the CAE industry has evolved rapidly. Process analysis tools have been developed which provide a unique source of predictive engineering information, not only about plastics flow in the mold filling phase, but also the packing and cooling phases of the process as well as shrinkage and warpage phenomena. By the 1990s, simulations of alternative molding processes were introduced, including gas-assisted injection molding, co-injection molding, injection compression molding and reactive molding processes using thermoset rather than thermoplastic materials.

Concurrent advances in material technology, testing techniques and data modeling improved analysis results from filling through warpage for semi-crystalline and fiber-reinforced thermoplastics as well as thermosets such as epoxies and encapsulant materials used for electronics packaging. Results of validation studies comparing simulation results to experimental data using different materials and material data models are presented in this issue of Flowfront; see “Moldflow Leverages a Decade of Mold Trials to Augment Extensive Product Validation Efforts.”

Still, the cumbersome requirements of midplane modeling and the relatively rigorous qualifications required of users were a formidable barrier to widespread adoption of the technology. Until the 1990s, CAE analysis was mainly for experts, not everyone.

Evolution in Modeling

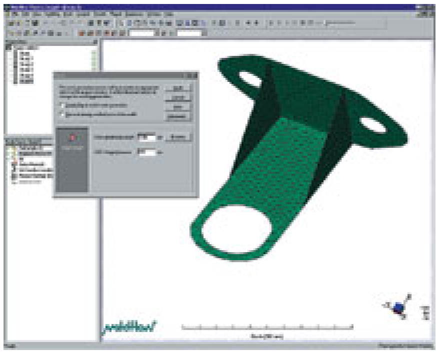
In the days when most common CAD systems were based on surface or wireframe modeling and thickness was never shown explicitly, the path was clear and direct from the CAD model to the midplane model used for finite-element analysis.

With the advances in solid modeling that have burgeoned since the early 1990s, CAD models now represent the part, including its thickness, in detail. Solid modeling has become the norm, because the solid model can be the master not only for design but also for all downstream operations, including rapid prototyping, assembly analysis, tolerance analysis and mold making.

The adoption of solid modeling introduced a problem for many plastics CAE users. Because the traditional finite-element simulations required a midplane representation of the part geometry, solid models had to be modified to generate an appropriate model, or a separate model had to be created just for plastics CAE analysis. To overcome this problem, plastic CAE suppliers have pushed the technology in two directions: developing methods of manipulating solid models to work with traditional finite-element analysis techniques, and developing true three-dimensional (3D) simulations to work directly on the solid models.

Automatic Midplane Generation

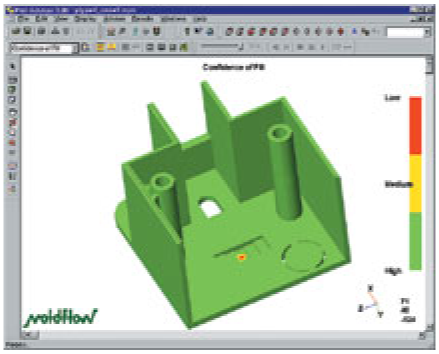
This is the direct approach in which a solid model is read into a program and a midplane mesh is generated automatically. In practice, the fully automatic generation of a midplane model is difficult. In many cases, it is necessary to clean up the resulting model before it is appropriate for analysis. Nevertheless, midplane generation can save an enormous amount of time for many types of parts.



Automatic midplane generation technology transforms 3D solid geometry to a midplane mesh model with minimal user intervention.

Dual Domain™ Technology

Dual Domain finite-element analysis is a patented method that enables analysis on the solid model using conventional process simulation methods. It uses a surface mesh on the solid geometry and then inserts extra elements to ensure that the filling pattern is physically reasonable. The technology was so named because in fact two finite-element analyses are performed, one on each side of the component. Dual Domain technology has had a striking impact on plastics CAE since its introduction by Moldflow in 1997. Remember, typically plastics CAE has been seen as a specialist activity. Dedicated analysts who were experts in the use of the software and had a good understanding of injection molding theory performed simulations. While it widely recognized that simulation performed early in the design stage provides more benefit, the lack of direct interfaces between the CAD systems on which parts were designed and CAE software meant analysis was separate from the design environment. Dual Domain technology removed this barrier: it is now possible to couple plastics CAE closely with solid modeling.



Dual Domain technology brings CAE analysis capability to non-specialists. Intuitive results displayed in Moldflow Plastics Advisers products make it even easier for part and mold designers to reap the benefits of simulation early in the design process.

This type of technology redefined the use of CAE analysis for plastics by enabling non-specialists to perform analysis very early in the design stage. Accordingly, special attention was paid to results presentation. Whereas the traditional outputs have been pressure and temperature distributions, new display technology has been introduced in response to the fact that the designer may have little previous experience in plastics CAE. For example, to choose the number of gates, wall thickness, and resin type, the pressure required to fill the part becomes a critical variable. This in turn depends on the temperature of the material, and this in turn depends on the processing conditions, locations of gates, and the part geometry. Determination of the pressure required to fill is therefore a multi-dimensional task that requires simultaneous interpretation of pressure and temperature distributions. To simplify the interpretation of results, the pressure and temperature distributions are processed to produce a single plot called "confidence of fill." This is displayed according to a traffic light analogy, by overlaying the colors red, yellow and green over the part geometry in areas that have low, medium and high probabilities of filling, respectively. Such a plot is far easier to understand than the simultaneous pressure and temperature distributions.

Dual Domain technology enables plastic designers to begin analysis very early in the design phase. However, the information discovered here is valuable only in so far as it can be communicated rapidly to other people involved in the process. For example, material suppliers, mold designers and the molder can all benefit from this early knowledge of how the part will fill.

CAE suppliers have taken advantage of the rapid development of the Internet as a way to facilitate communication among team members. Already many companies are linking to the Web to facilitate report generation and communication as well as Product Data Management (PDM). Moldflow offers an Internet-enabled version of its Moldflow Part Adviser product, based on Dual Domain technology, which can be licensed on demand over the Web. Users pay a fee to license a particular geometry model for unlimited analysis runs, allowing various gate locations, material choices, and processing conditions to be evaluated.

Dual Domain technology not only provides the means to take analysis into the design stage, but advanced analysis modules based on Dual Domain technology are also available. This means that designers who encounter problems can send their models to analysts armed with advanced products for detailed analysis. In this way, Dual Domain technology reinforces the link between the traditional CAE user and part designers. The result is that more designs are subject to analysis and parts can be modified, if necessary, at a stage where change is least expensive.

True 3D Analysis

All technology discussed above works best on typical, thin-walled plastic parts. Three-dimensional analysis technology eliminates this requirement - it is possible to simulate molding of parts for which a midplane is not easily generated. Such parts are generally thick and chunky or have extreme thickness changes. In addition to broadening the range of parts that can be simulated, 3D analysis also couples well with solid modeling: the model for analysis is an unambiguous representation of the real part geometry.

Read about Moldflow's latest developments in 3D technology in this issue of *Flowfront*; see "Moldflow Plastics Insight 4.0 — MPI/3D Enhancements."

Design and Process Optimization

One of the most exciting areas for simulation is the potential to optimize part designs and the manufacturing processes.

Simulation has always been used to improve part designs, and while this is a form of optimization, here the term refers to an automated procedure to improve part designs or obtain an optimum set of manufacturing conditions.

Initial efforts to optimize part designs have focused primarily on sizing runners for family and multi-cavity tools. A series of flow analyses are run, usually subject to the constraint that the cavities all fill at the same time. Runner dimensions are defined to lie in a range, and the optimization algorithm varies the diameters of the runners subject to the constraints until a satisfactory solution is obtained.

More recently, there has been interest in optimizing the manufacturing conditions used to mold the part. Much of the motivation for this work stems from the possibility of using simulation results to provide information to the injection-molding machine, but here we consider the scope of optimizing processing conditions.

For the filling phase, it is known that many surface defects may be caused by sudden changes in the flow front velocity. Thus, a common constraint is that the flow front velocity be constant. In attempting to achieve a constant flow front velocity, one must be careful to ensure that the material shear stress limits are not exceeded and that the temperature of the material is within permissible limits. By considering these factors, optimization algorithms can define a ram profile that meets these conditions, which can be entered on the molding machine directly.

The packing phase has a dramatic effect on part quality, particularly part weight, dimensional tolerance, and warpage. In the packing phase, material is subjected to high pressure while it cools in the mold. The pressure-temperature history determines the density of the molded material; therefore, a common goal of optimization is to minimize density variation throughout the part. It also is possible to minimize variation in linear shrinkage in the flow and transverse-to-flow directions.

Machine and Process Control

While simulation technology has advanced rapidly, it is primarily targeted at the part design and mold design areas of injection molding. Of course, the actual processing of the material has a dramatic effect on the quality of the component, and much effort has been devoted to controlling the injection molding machine. Much of this effort has been focused on ensuring that the molding machine is capable of repeating a particular cycle. While this is certainly important, the part quality is affected by the polymer flow. Much of the focus in machine control has been on making the machine respond rather than manipulating the melt. Moreover, injection molding machine controllers do not provide systematic tools for optimization of the molding cycle.

These considerations led to an effort to bridge simulation with injection molding machine controllers. The aims of this endeavor are twofold: ensure that the results of simulation are able to be used in production, and ensure that if simulation has not been done, there is a systematic way to optimize a given mold, material, and machine combination.

In October 1998, Moldflow released its Moldflow Plastics Xpert® (MPX®) product line with its focus on process setup, optimization and control. Through the acquisition of Branden Technologies in March 2001, Moldflow's shop floor offerings expanded to include Shotscope® process monitoring and analysis technology. Today, MPX and Shotscope capabilities have been merged into a single operating environment and common hardware platform and evolved into Moldflow Manufacturing Solutions™ (MMS™) product line. MMS products comprise a complete suite of tools that can be used for the setup, optimization, and control of the injection molding process, as well as for process and production monitoring and related tasks. One of the main features of this product line is that it utilizes the existing instrumentation on the molding machine. The January 2003 acquisition of Dampmart, France-based CPI provides production monitoring technology that will enhance future releases of MMS software.

Read about the first release of MMS software in this issue of *Flowfront*; see "Injection Molding Process Automation Technology for Surviving in a Global Economy."

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