Modeling **Dies for Rubber Parts**

Computer simulation helps reduce extrusion cost by 50 percent.

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Derby Cellular Products specializes in producing molded, extruded and fabricated ethylene propylene diene monomer (EPDM) polymeric seals for automotive, truck, agricultural, off-road, air filtration and appliance markets. The company recently found it difficult to profitably produce an EPDM environmental seal for a complex geometry. The initial plan was to produce the part using a single-cavity die. As a result of the complex geometry, approximately 20 trials on the extrusion line were required at a total cost of about $16,000. Rather than continue attempts to optimize the single-cavity die, Derby Cellular Products decided to use computational fluid dynamics (CFD) to evaluate whether or not the part could be produced using a two-cavity die. This application would also serve as an excellent platform from which to assess CFD's capabilities in general.

CFD simulation of extrusion processes provides information about flow patterns, including velocity, pressure, shear stress and temperature values, as well as hang-up areas within complex dies and manifolds. As part of the analysis, the die designer may investigate how changes in the die internals or feed ports affect the exit flow uniformity (die balance). CFD can also be used to calculate the extruded shape from a given die, facilitating detailed parametric studies that significantly reduce experimentation, design cycle times and costs.

Most CFD software is unable to handle complex polymer flow problems involving nonlinearities such as viscoelasticity, shear-thinning, viscous heating, free surfaces and irregular geometries. POLYFLOW software from ANSYS, Inc. was selected to perform the analysis because it provides the above capabilities, as well as a unique inverse die design feature. After specifying the desired profile shape and material properties, this feature instructs the software to compute the required die lip and adaptor shapes. POLYFLOW software also provides a library of rheological models capable of dealing with the material nonlinearities involved in polymer flows.

The dual-cavity extrusion die was modeled by importing a solid model of the initial concept into POLYFLOW software for die flow balancing. The geometry, which was in STEP file format, was imported into the GAMBIT pre-processor for geometry cleanup, identification of the fluid volume and creation of the volume mesh needed for CFD analysis. The boundaries for the 3-D CFD die model included a back plate wall containing two inlets, a middle transition or adapter plate wall and, finally, the die land wall and material outflow area. The two cavities begin in the die plate. The die land length plays a vital role in determining the die swell factor. During the mesh creation process,

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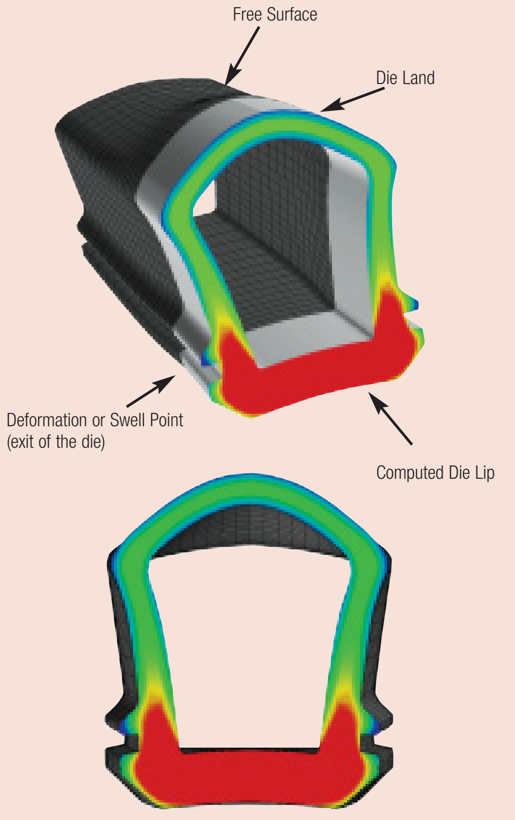
Polymer seals produced by Derby Cellular Products are used in a variety of automotive, agricultural, filtration and appliance applications. One such application is the door seal for a dishwasher.



Velocity profile across a die land inlet section. Using the inverse die design capability of POLYFLOW software, the die land can be automatically created to generate the correct extrudate after all deformations.

Dual extrusion of ethylene propylene diene monomer seal

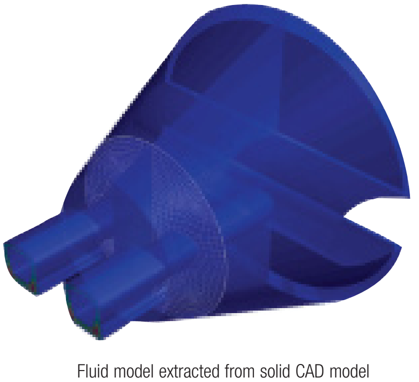
particular care was taken to ensure that the mesh was fine enough to provide adequate coverage and solution detail of the thinner regions.

Initially, the flow of polymer through the die was simulated to balance the flow between the two cavities. Then, several cases were modeled in which the effect of modifying operating conditions on flow behavior through the die was examined. It was determined that increasing the die land length reduces the swell factor of the polymer because the additional residence time in the die land area enables the polymer molecules to properly align along the flow direction.

After balancing the die completely, an inverse extrusion analysis was run to determine the die lip geometry. First, simulations were run to examine the role of the wall slip factor on the resulting profile and to determine the wall slip coefficient, which plays a critical role in the inverse extrusion analysis used to calculate the correct amount of die swell. While classical Newtonian fluids consisting of small molecules tend to stick to a wall, polymeric fluids consisting of long molecular chains have a tendency to slip along a wall at high pressures, and the amount of slip has an important effect on the extrusion process.

To optimize die lip geometry, a 3-D CAD model consisting of two sub-domains was constructed. One sub-domain contained the die land and the other contained the free surface that extended beyond the die lip area. An assumption was made that the polymer would slip along the die wall at a speed that is 25 percent of the average inflow velocity. Several slip coefficients were tried until one was found that achieved the desired 25 percent velocity ratio. This value was then used to run the inverse die extrusion and determine the lip geometry, while simultaneously determining the swell factor of the material coming out of the die lip and adjusting the die land geometry required to achieve the desired product shape. Using this die lip, the simulated adapter and back plate inlets were balanced for both cavities.

Finally, the dual-cavity die was fabricated and run on the extrusion line. The resulting profile shape was close to, but not exactly the same as, the desired geometry. As a result of the discrepancy in the profile shape, the polymer was slipping more than 25 percent against the die wall. Subsequently, the model was adjusted by changing the slip coefficient to a level that represented the actual conditions. The inverse die simulation was then repeated and a revised lip geometry was generated. Following this simulation, a new dual-cavity die was fabricated, and, when tested on the extrusion line, it produced a profile that matched the desired geometry. By using simulation to replace the time-intensive trial-and-error process employed previously, the cost of producing the part was reduced by approximately 50 percent. ■



Fluid model extracted from solid CAD model