

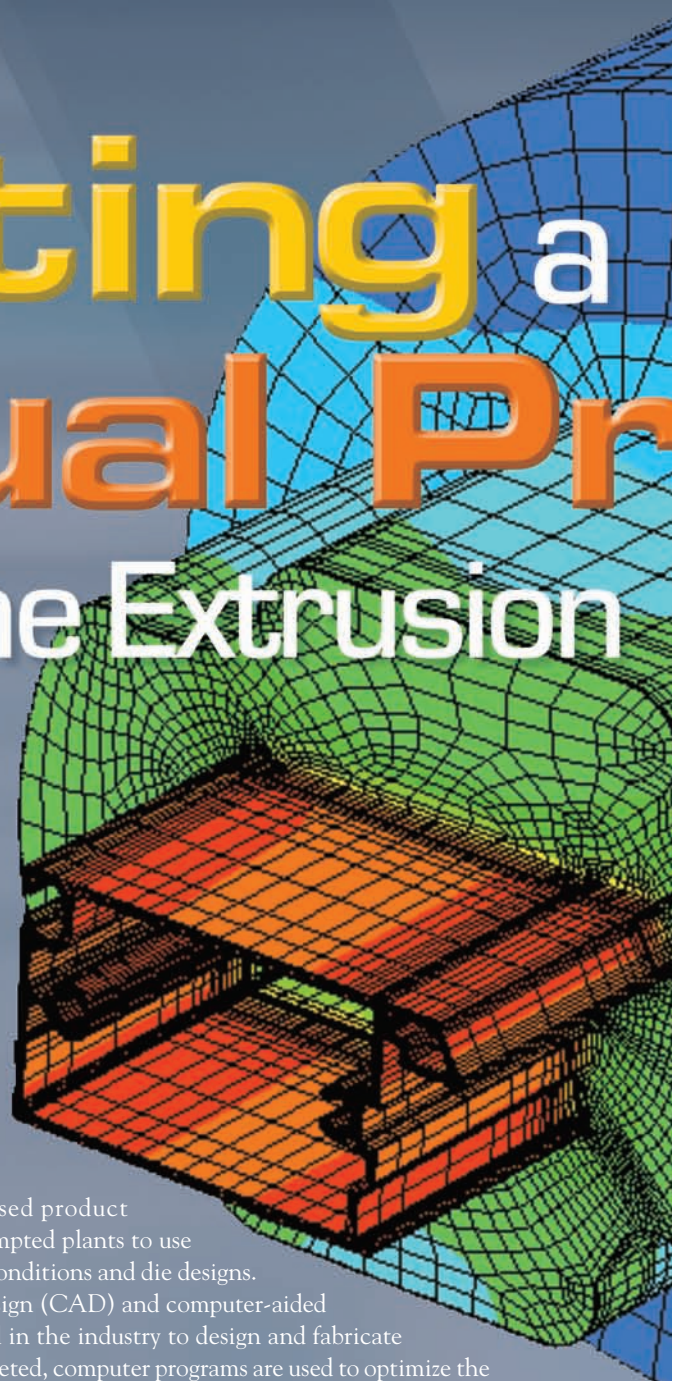
# Creating a Virtual Press to Optimize the Extrusion

Today's advanced computational tools **increase productivity and quality**, as well as **lower energy consumption** in the design and fabrication of extrusion dies.

**D** by Mahender Reddy

Demand for higher extrusion rates, increased product quality and lower energy consumption have prompted plants to use various methods to determine optimum process conditions and die designs. Computational tools, such as computer-aided design (CAD) and computer-aided machining (CAM) software, are commonly used in the industry to design and fabricate extrusion dies. Similarly, once die trials are completed, computer programs are used to optimize the extrusion process and reduce scrap.

Extrusion die design is still an art that depends heavily on previous experience and die trials to fabricate a single die. While the use of computational tools to simulate material flow and correct the die designs is still in the early stages of implementation, computer modeling of the material flow and heat transfer during extrusion can serve as a virtual press and reduce die trials.



# Process Process

## Eliminating the Guesswork

Computer programs are commonly used to optimize process conditions, reduce scrap, schedule jobs and track orders. These process optimization programs typically use a feedback system loop to adjust extrusion speeds, using the exit temperature with the aim of achieving isothermal extrusion conditions.

Such systems are capable of dynamically updating the process conditions from billet to billet and recommend near-optimal press speed and billet preheat. This approach, however, still requires that the extrusion engineer guess process conditions for the first billet.

Analytical techniques such as the upper-bound theory can be used to eliminate this guesswork. These analytical methods determine the process parameters by solving equations that govern

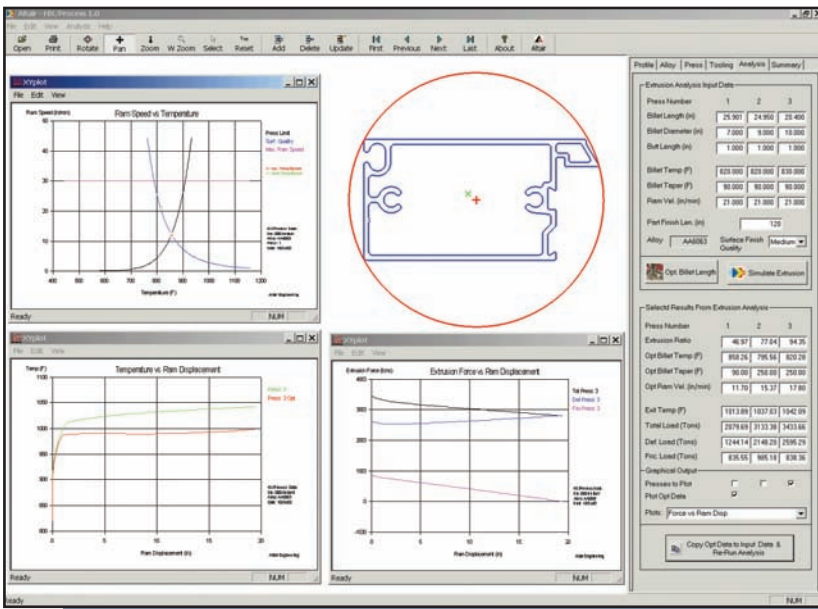


Figure 1. Altair HyperXtrude/PROCESS – Extrusion process optimization software.

deformation of material during the extrusion process.

Some analytical tools like Altair HyperXtrude/PROCESS include higher-order terms in their formulation. The expressions for pressure and temperature derived from upper-bound theory are modified using results from press data and advanced numerical methods.

The model uses press capacity; container diameter; temperature and strain-rate-dependent alloy properties; die shape; and geometry of the profile to compute the extrusion limit diagram. This extrusion limit diagram (Figure 1) is then used to determine the optimal extrusion speed, billet preheat and taper.

The main advantage of this approach is that it is general enough to be applied to many different alloys. With the self-check graphs, the user can maintain surface and dimensional integrity from the very first extrusion of a new die. The temperature-versus-ram displacement graph shows the exit temperature increase due to deformation and friction. Based on this information, process conditions are adjusted to obtain an isothermal extrusion.

The extrusion limit graph allows the user to utilize the press to its maximum speed while maintaining the surface finish. In addition, this tool helps users to understand the velocity, pressure and forces exerted during the cycle. Knowledge of optimal extrusion speed, billet temperature and billet length helps increase productivity and reduce scrap.

## Analysis through Simulation

The process optimization tools just described are used during production. Prior to this, several die trials are carried out to balance the velocity distribution of the material extruded from the die. Even though die trials are costly and time-consuming, they are essential to ensure that the die produces extrusions of desired shape, tolerances and quality.

Reliable and accurate computer modeling of the material flow and heat transfer during extrusion is of great importance, as it can help minimize the die trials. Acting as a virtual press, it can also be used in designing the die and in troubleshooting problematic dies. Computer simulation also serves as the observer's eye to inspect and monitor the material behavior inside the die cavities as the material flows through it, where it is difficult – if not impossible – to make experimental measurements.

Numerical simulation tools such as HyperXtrude can be used to simulate material flow and heat transfer during extrusion. Depending on the type of formulation used, the finite-element programs developed to simulate extrusion can be classified into Eulerian codes, Lagrangian codes and Arbitrary Lagrangian Eulerian (ALE) codes.

In Eulerian codes, the mesh is independent of the deforming material, and they do not require remeshing. Lagrangian codes, on the other hand, track the movement of the material, and therefore require several remeshing steps and more CPU time to solve a problem. ALE codes adjust the mesh in preselected regions (such as die exit, billet, tool, etc.) to use a fixed mesh in other regions, and are best suited for extrusion die analysis. HyperXtrude is a finite-element method-based numerical simulation tool that uses the ALE approach and was developed specifically for analysis and design of extrusion dies.

There are several steps involved in analyzing an extrusion die. First, the pre-processing module reads a 3D CAD drawing of the die geometry. The user then creates a finite-element mesh representing the billet, die cavities, die assembly and container.

Next, the user inputs the process conditions, such as the extrusion speed; billet preheat; container and die temperature; as well as friction conditions at the tool and work-piece contact surfaces. The model data is then transferred to the solver module, which solves the transient and nonlinear equations to

compute the velocity, temperature, pressure and strain distribution inside the die.

The straightness and cross-sectional shape of the profile depend upon how well the die balances the material flow at the die exit. Balancing the distribution of flow through a die to achieve a uniform exit velocity is one of the most difficult tasks of extrusion die design.

Design of aluminum extrusion dies is complicated by the nonlinear constitutive relationship between flow stress and shear rate. Computer simulation of the extrusion process must take into account the nonlinear behavior of the material to accurately predict the velocity, pressure and temperature distributions in the die. A complete understanding of the flow field, temperature, load distribution and behavior of the metal under various operating conditions is essential to selecting and optimizing process variables, such as the extrusion rate, initial billet temperature and die design.

Wall thicknesses of extruded parts vary widely from 0.25 mm for a micro-multiport tube extrusion to more than 20 mm for heavy machinery components. Computational simulation tools must be capable of modeling a range of profile wall thicknesses. Figure 2a shows temperature of a micro-multiport tube profile as it exits the die. Figure 2b shows deflection of a hollow profile extruded through a two-hole die. The profile deflections are due to non-uniform velocity and temperature distribution at the die exit.

Extrusion is a time-dependent, discontinuous process, where the thermo-mechanical characteristics change as the billet is pushed through the die. It is important to simulate this transient behavior to obtain a complete understanding of the process. In addition, the model must be capable of simulating the friction at moving interfaces. Figure 3 illustrates the differences between direct and indirect extrusion processes.

During extrusion, large forces are applied on die surfaces that are in contact with aluminum. If the support for the die is inadequate, it will cause the die to deflect, thereby lessening its effectiveness. Therefore, a simulation tool must be capable of using the extrusion loads and predicting resultant tool deflection.

This requires a coupled flow, thermal and structural analysis model. Figure 4 shows the tool

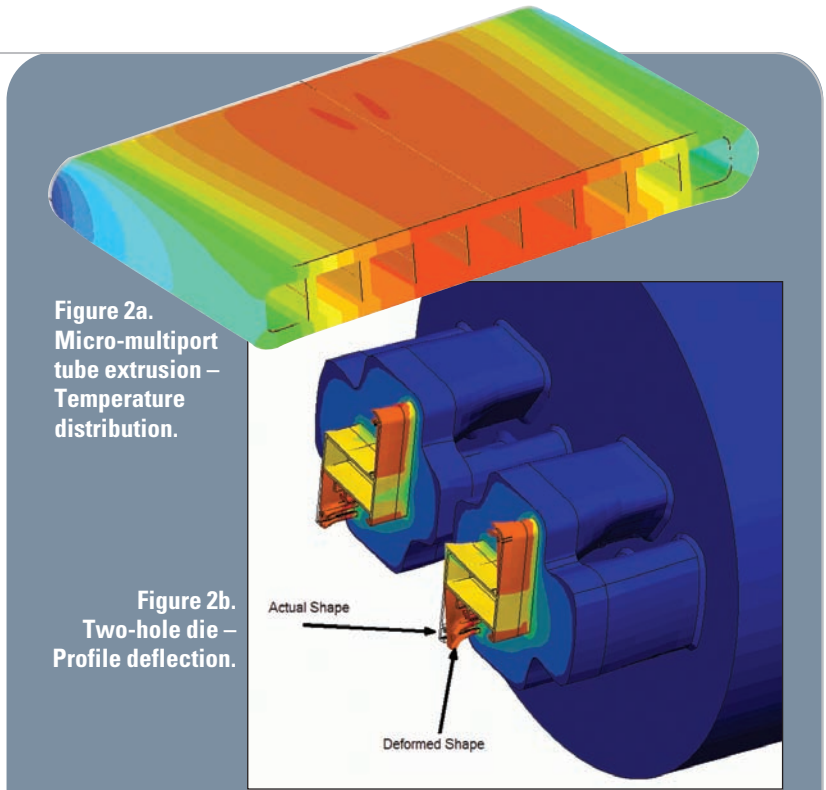


Figure 2a. Micro-multiport tube extrusion – Temperature distribution.

Figure 2b. Two-hole die – Profile deflection.

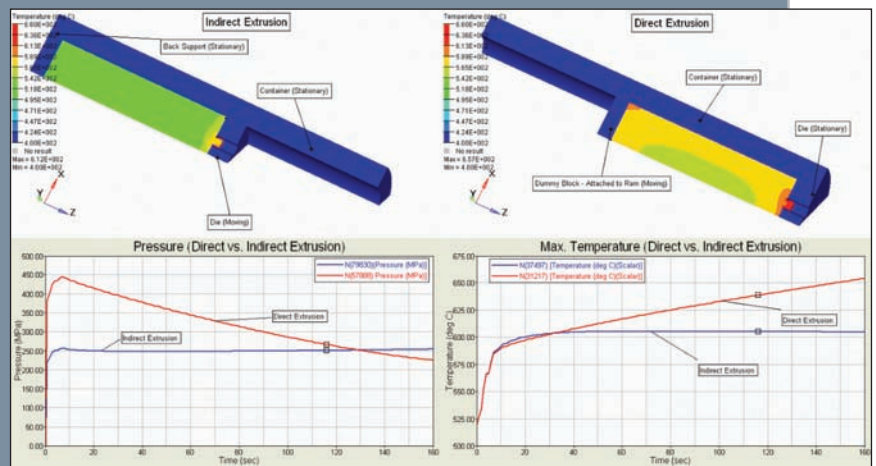


Figure 3. Comparison of extrusion pressure and exit temperature for direct and indirect extrusion.

deflection and resulting stresses in the die plate for a double-T profile die. Results from such analysis can be used to determine if the tool deflections are within acceptable tolerances. The resulting stresses can also be used to predict die life.

### The New Frontier in Die Design

The results from numerical simulation can be used iteratively to correct the die and eventually arrive at

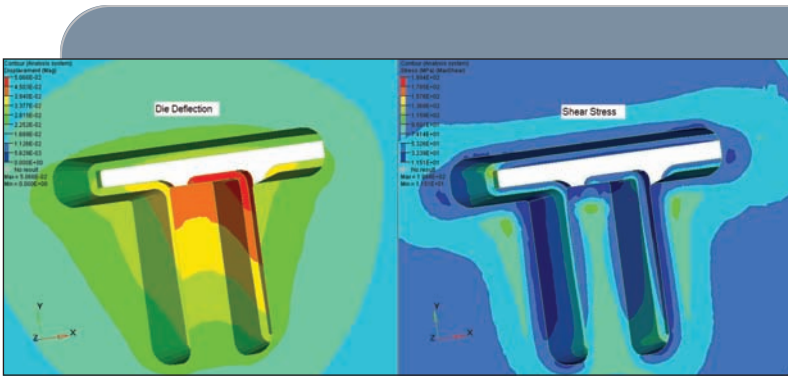


Figure 4. Deflection and stresses in die plate.

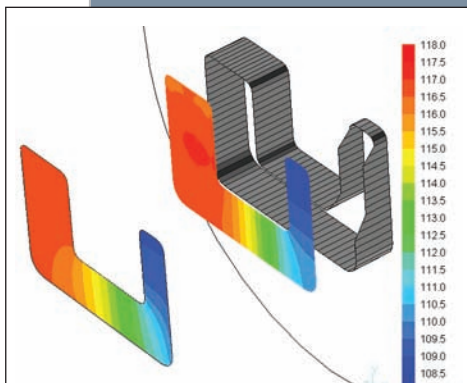


Figure 5a. U-Profile – Initial bearing shape and resulting exit velocity.

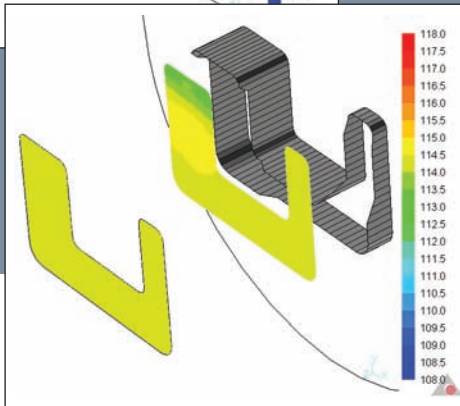


Figure 5b. U-Profile – Optimized bearing shape and resulting exit velocity.

an optimal design. For large problems, these numerical die trials can be time-consuming. An alternative is to use an optimization algorithm to compute optimum bearing lengths and porthole shapes.

This method involves coupling a finite-element model for flow analysis with a design optimization method. A measure of uniformity of the material distribution at the die exit in response to minor perturbations in the design variables can be used to correlate the flow behavior with the design variables. The optimization engine automatically develops this correlation by driving the finite-element model – controlling its input data and monitoring the extracted solution. Based on this correlation, design variables are modified incrementally, and the

solution steps are repeated until the design satisfies the objective functions and constraints.

Typically, for extrusion die design, the objective functions state that the average velocity and/or the average temperature across the die exits are uniform. Constraints are used to limit the overall length of the bearing or match the existing hardware in some regions of the die.

As an example, this approach is used to optimize a die for the U-profile shown in Figure 5a. In this case, Altair HyperStudy, a multi-disciplinary optimization tool, and HyperXtrude are used to perform the design optimization. Figure 5a shows the non-uniform velocity at the die exit for initial bearing configuration for a U-profile extrusion die. As shown in Figure 5b, the design optimization process results in a new bearing shape that provides a uniform flow at the die exit. By incorporating design optimization methodologies into numerical die trials, further savings in both time and resources can be realized through a reduction in the number of design iterations required to achieve design and quality objectives.

### Performance Up, Problems Down

The use of simulation tools and computers are limited to the die design, fabrication and production stages of the extrusion process. Extruders can reduce and eliminate costly and time-consuming die trials using numerical simulation tools to analyze dies. Computational methods can help identify and correct flow imbalance at the die exit, which, in turn, serves as a virtual press to help reduce or eliminate die trials and increase productivity.

As the usage and capabilities of these analytical tools continue to expand, extruders will benefit from a deeper understanding of die attributes as they relate to part quality. Virtual simulation provides a cost-effective approach to maximize production performance and correct problem dies – before they hit the plant floor.



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The above article is an excerpt from an editorial section called "Leveraging Computer Technology to Improve the Extrusion Process" in the April 2006 issue of *Light Metal Age* magazine ([www.lightmetalage.com](http://www.lightmetalage.com)).

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