Simulation Aided Extrusion in the Design Practice

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Introduction

To fulfill the demand for complex profiles with critical shapes and alloys, tight tolerances, and to improve die life and productivity for industry, specifically automotive and transportation applications, advanced modeling techniques are being integrated in the die design phase. The MTD numerical modeling is a proven technique to help designers develop complex extrusion dies and to optimize production parameters, for both small and large presses.

The efficiency of numerical modeling in practice essentially relies on its tight integration within the die conception and process optimization. We call such symbiotic procedures Simulation-Aided Extrusion. In the present paper we illustrate and comment on one of MTD's standard procedures, which is based on 3D simulation and may depend on a variety of critical aspects (tolerances, shape, alloy, higher-speed die, weld seam quality, die life, mechanical resistance, etc). Furthermore, MTD Simulation-Aided procedure is illustrated on the basis of practical design cases which were performed for different customers.[1-5]

Simulation and Extrusion

The MTD Simulation-Aided Extrusion approach includes 2D and 3D models of different complexity. The models were gradually developed, improved, and calibrated in industrial environments during the last decade. They result from a combination of technical knowledge, adequate model hypotheses, calibrations based on trials, numerical experiment design, and automated computational procedures, such as the MTD seamless meshing and algorithmic developments to boost computational speed.[6]

There are two main classes of models (Figure 1). First are the models given by analytic formulae, or by finite element computations using 2D and 3D seamless mesh. Such models, which run quickly (execution times in the order of one minute), are being made user-friendly so that the die shop or press operators can exploit them daily, in an interactive manner. Second, the more complex 3D models need more preparation and runtime.

User friendly models are being fully integrated in die shops and production sites for daily use on-site. They include, for example, the MTD Automatic Bearing Calculator (ABC), which is being used in die shops, and the Heating and Cooling Simulator (HCS), which simulates profile quenching. Details concerning those programs have been presented elsewhere.[7]

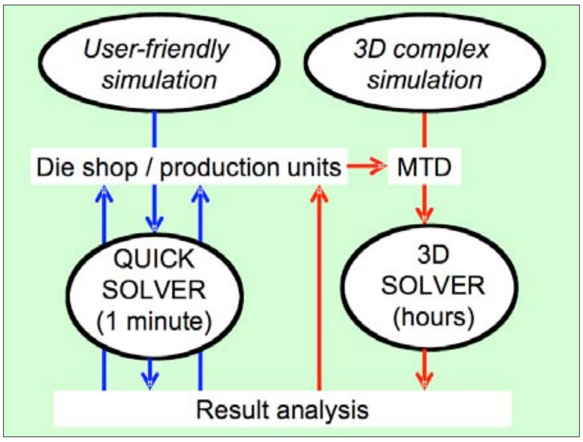

Figure 1. The two modeling levels of Simulation-Aided Extrusion.

The 3D Design Optimization Procedure

Contrary to the easy-to-use models just mentioned, 3D models cannot yet be used directly by press operators or die designers. For such complex cases the optimization procedure runs as follows (Figure 1):

• The customer (extruder) provides the profile drawing, and fills out a check-list (technical details, alloys, and press data)

• MTD performs a starting die design and optimizes it by numerical simulation (3D flow balance and pressure field, full cycles transient 3D computation, stress and deformation, and bearings)

• Prior to releasing the new die for production, it is certified by MTD

MTD experts provide a full on-site support service when launching first production with a new die, including a corrector service. The full optimization loop takes between a few hours and a few days, depending on the complexity of the problem.[6] The MTD 3D simulation provides support for the extrusion of difficult profiles (critical shapes and alloys), improves product quality and weld seams (for industry, specifically automotive and transportation applications), reduces the number of trials, improves die life, and increases extrusion speed for big runners. Various types of simulations are available that correspond to well-defined classes of technological questions, such as:

• Die life and problems of cracks in dies. Here one resorts to 3D thermo-mechanical modeling of the die. This is particularly important in the case of hard alloys, and sometimes it is a critical issue for large dies.

• Flow-balance and weld seam problems. For this type of computation one resorts to 3D flow simulation. To ensure flow balance it is useful to simulate 3D aluminum flow and pressure through the die at the design stage. This allows for reduction of the number of press trials and die corrections. A detailed knowledge of the pressure in the weld chamber also helps to design dies for improved weld seams.[8]

• Extrusion speed and press cycle optimization. Here one has to perform 3D transient simulation of temperature evolution of the press during extrusion. Flow balance is crucial for high-speed dies. To perform the simulation, the solver takes convection (aluminum flow), heat conduction, and local viscous heat sources into account. Years ago, the models were calibrated by comparisons with measurements on industrial presses. These calibration and the model details were presented at ET'04.[10]

Die Stress and Deformations

Mechanical stress is an important issue in die making, especially for large dies, but also for smaller ones, depending on the geometry. Local excessive stress leads to cracks, plastic deformations, and fatigue, i.e., premature degradation of the profile tolerances and reduced die life.

3D stress and deformation is caused by both aluminum pressure within the tooling during extrusion and thermal gradients which lead to thermal stress. Both effects are taken into account in the MTD modeling. Mechanical computations are performed on the pressure, flow, and thermal simulated 3D fields. The model is based on the standard 3D formulation of the linear deformation problem. Plastic behavior is irrelevant, since the goal is to remain below the elastic limit. Most important, however, is to take thermal stress into account, since in many situations this effect is of the same order of magnitude as the stress due to mechanical load during extrusion. In many cases, the thermal gradients reduce the stress under the bridges on the core side. To take advantage of this effect, especially in the case of large dies, one has to press carefully during the first cycle, and wait until adequate thermal conditions are satisfied, before extruding at full power.

To illustrate stress modeling in the die design phase, the following example shows that the original design[4] may lead to critical stress under the bridges of the order of 1,500 MPa, which is much too high (Figure 2). Here the mechanical resistance is improved by increasing die thickness and bridge widths, thus the maximum stress is reduced to 700 MPa, which is uncritical.

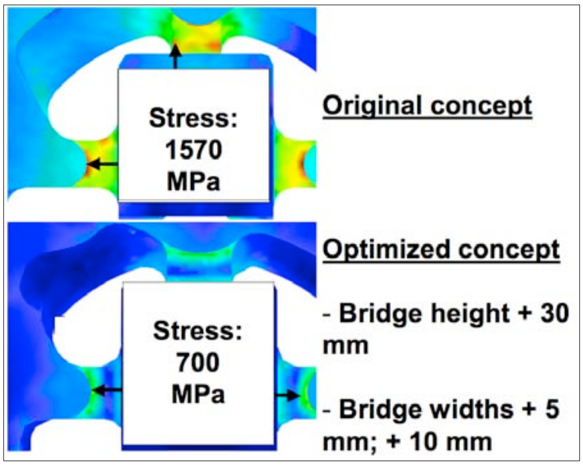

Figure 2. High mechanical stress under bridges is reduced by half, when increasing the bridge widths by 5-10 mm and height by 35 mm.

Computation of 3D Aluminum Flow and Pressure in Dies

Flow balance is a key issue in die making. Even when the design is acceptable, one should avoid balancing the flow with bearing lengths only. Too much contrast in bearing lengths causes instabilities and superfluous heat production, resulting in productivity losses. For high speed dies the bearings should be as constant as possible. To illustrate the application of flow modeling in die design, the example of a double tube profile is presented (Figure 3).[3] The tooling system includes two cores and a die as shown on Figure 4. To compute flow through the die, the CAD assembly, including the container, has to be completed by the aluminum CAD (Figure 5), from billet to exit (profile).

Starting from the basic design (3D CAD), a first flow simulation is performed. As a result, the exit velocities through the internal tube are too small, i.e., the relative flows through the external and internal tubes are unbalanced. The design was modified, to favor flow through the internal die alimentation and reduce external flow. The result is shown in Figure 6. In the present example, the modifications turn out to be slightly exaggerated, thus the final solution was obtained by fine tuning.

To improve flow balance, modifications of the design were made. Another design optimization example is shown in Figure 7. In this case, the difficulty was to guarantee very tight profile tolerances and to prevent deflec-

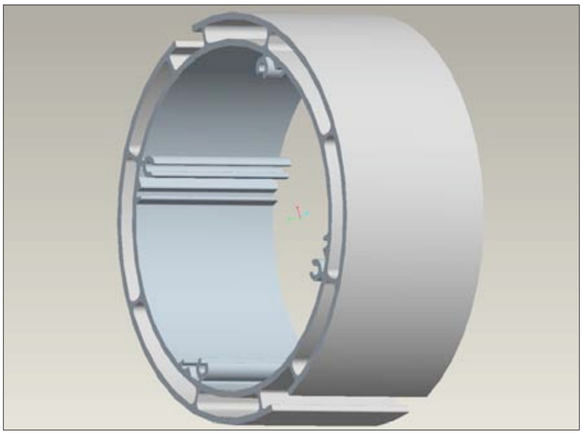

Figure 3. Double tube profile.

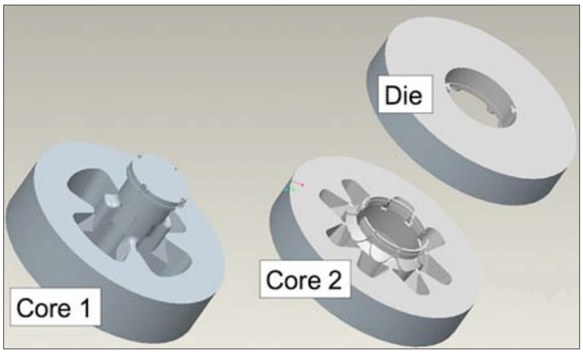

Figure 4. The two cores and the die of the double tube profile. Original design[3] was modified after simulation.

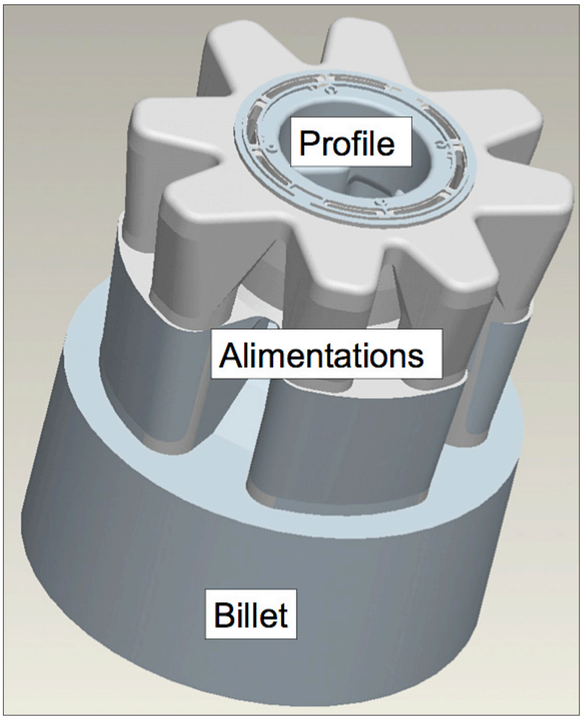

Figure 5. The aluminum flows through the tooling system for the double tube profile.

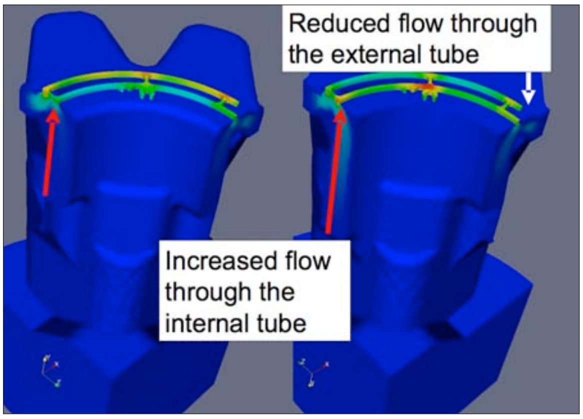

Figure 6. The left image shows the computed exit flow corresponding to the original die concept.

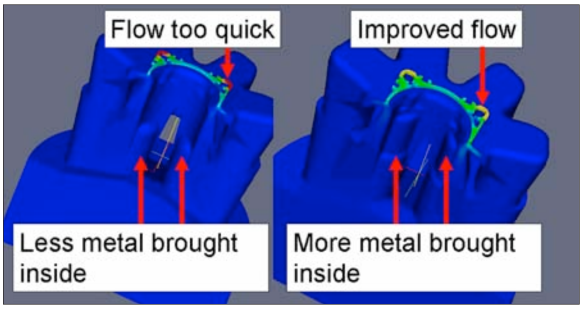

Figure 7. The core is modified so that more aluminum flows through the internal part, thus reducing the excess flow through the profile corners.

tion of the small mandrels. The original design[3] gave rise to excessive flow in the corners. The design was modified so that more metal is brought to the internal die alimentations. This improves the flow balance.

These examples show that flow balance can be improved in practice by 3D flow simulation. Furthermore, it is very interesting and useful for the designer to be able to test original ideas, quantify the effects, and gain experience in fine tuning of extrusion dies. Flow simulation also opens the opportunity to test new design ideas, prior to a real extrusion trial.

3D Press Cycle Simulation: Virtual Extrusion

Realistic process simulation is important for the prediction of the optimal extrusion speed associated with a given tooling system and process conditions. Such a virtual extrusion, performed on PC, allows the user to play with the parameters (speed, initial temperatures, pre-heating, taper, alloy, recipient thermal regulation, dead times, etc). The detailed analysis of temperature evolution also helps to improve die design, and local overheating can often be reduced by adequate modification of die geometrical details.

To simulate press cycles, one performs a 3D transient simulation of temperature evolution of the press during extrusion. The simulation takes convection (aluminum 3D flow), conduction, and local viscous heat production into account. The simulation of the extrusion process[9] (virtual extrusion) runs in the same way as real extrusion. The geometry of the tooling system, recipient, and support system are given (3D CAD). Initial conditions (temperatures, regulation systems) are defined. In particular, the billet dimension, alloy, and taper are given, as well as extrusion speed and dead times. Then the billet is placed into the container and the process starts. At the end, after a given dead time, extrusion starts again with a new billet, and so on. Figure 8 shows the simulated exit profile temperature of a large tube, in which the piston speed was increased gradually, thus resulting in a profile temperature increase of about 20°C. Here the dead time between cycles is 110 seconds and the cycle time is about 10 minutes.

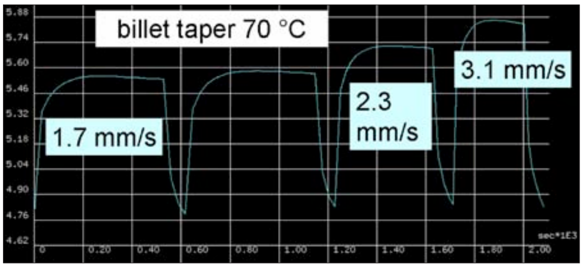

Figure 8. Simulation of press cycle with increasing extrusion speed. Temperature is plotted vs. time.

It is useful for the operator to be able to test the press by virtual extrusion, and investigate the working window (in particular the maximum extrusion speed), and try the effect of different billet pre-heating temperatures with or without taper, recipient temperatures, and so on. The process simulation predicts the local profile temperature at the exit as a function of time during extrusion. Therefore, it is possible to test different die designs[5] by virtual trial. Figure 9 shows two designs that are considered, with and without central alimentations. Central feedings lead to reduced profile temperature and higher productivity.

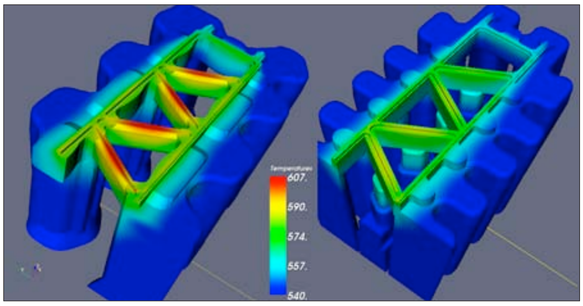

Figure 9. Simulated temperature at the end of a press cycle. On the left, excessive temperatures are observed in the central legs. Central alimentations, shown on the right, are beneficial for this geometry.

Conclusion

The utilization of computer models has been shown to be the most useful in aiding the extruder and die designer in the day-to-day practice of designing complex applications for industry, specifically automotive and transportation. Improvements in the conception of new design has allowed a reduction in the number of trials, better control of dimensional tolerances, improved product quality, and increased die life and extrusion speed. Numerical simulation, however, is of no use as a standalone tool. To be efficient, it has to be integrated within classical die and process design approaches and tightly combined with practical experience in die shops and production units in a closed loop process.[2] In that respect, MTD has developed, improved, and optimized its models over the last decade, taking into full account real industrial conditions.

Editor's Note: For more information, contact Yves Krähenbühl by email at: yves.krahenbuhl@m-td.com.

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