How Die Diameter Affects Stress on the Mandrel in Direct Aluminum Extrusion

By Tommaso Pinter, Almax Mori

Editor's Note: "FEA in Extrusion Die Design" is an ongoing series dealing with the opportunities that finite element analysis (FEA) offers to the extrusion industry. Topics will include addressing extrusion defects through die design, the effect of die design on aluminum microstructure, novel approaches to prototyping, and more.

Among the various profiles that can be manufactured in direct extrusion, hollow profiles are marked by a higher level of complexity compared to solid profiles. This is due to the need for a porthole die, which requires a mandrel supported by two or more legs (or bridges) in order to define the internal shape of the profile. The main drawback of porthole dies is their increased deflection under process loads, which is caused by a progressive accumulated plastic deformation that can lead to the profile going out of tolerance. In this respect, the amount of accumulated deformation correlates to the specific service conditions resulting from creep-fatigue. Fatigue manifests over time during extrusion, since each extruded billet represents an additional loading cycle for the die. In addition, because of the high process temperatures and significant cycle times during the extrusion process, the creep phenomenon has to be accounted for when considering die life prediction.

Die vendors are required to manufacture porthole dies capable of producing a required profile section within tight tolerances while achieving high production rates, as well as with the shortest front-end defect and the lowest knock-off rate. Last but not least, die life is also very important, as it directly influences the transformation cost of extrusion.

During the die engineering phase, accurately estimating tool stress under load makes it possible to predict whether or not a mandrel might be subject to permanent plastic deformation. This is also important for optimizing die geometry to achieve the lowest peak stress on mandrel legs in order to optimize the operating life of the die.

The most effective way to predict the tool stress of a die and, thus, its operating life is through the implementation of FEA, which is becoming one of the most important tools for process and product optimization in the extrusion industry. In this context, the case study presented here was aimed at predicting the influence of die diameter over the stress and displacement of the mandrel section of a porthole die. Specifically, the study compared the behavior of an optimized die with one having an increased outer diameter.

Case Study

The aim of the case study is to understand how a bigger die size affects the stress of the mandrel section. The AA7108 profile used in this case study is a hollow section (Figure 1) that would be extruded in a single exit press using a 13 inch billet container. Figure 2 shows the die geometry used for the simulation. This includes two Butterfly Die™ designs using H11 tool steel, which vary only in terms of the outer diameter of each die. Specifically, the first die set is 14 inches x 12 inches and the second die set is 17 inches x 12 inches, with both using the same bolster of 22 inches x 12 inches.

Coupled simulations were performed using the Mechanical Engineer Suite from Altair Engineering. Ram speed was set at 24 inches per minute and the billet length at 42 inches. The pre-heating temperatures of the die, billet, and liner were fixed at 860°F, 896°F, and 800°F, respectively.

Based on the pressure and thermal loads coming from the steady state simulations, element tool stress analysis was performed using the multi-physical environment Altair SimLab™. In order to reduce the computational time, only the die and bolster were modeled during the study, while the pressure ring was treated as a rigid entity.

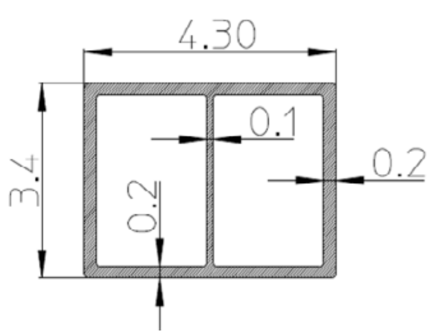

Figure 1. AA7108 hollow section extruded using a press with a 13 inch container (values in inches). Nominal weight is 3.9 lbs/ft and the extrusion ratio is 41.

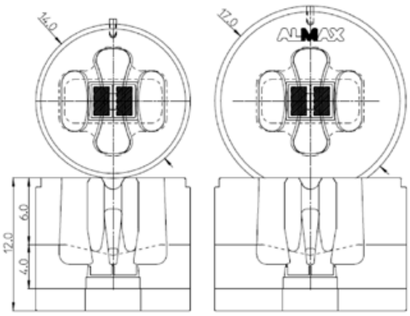

Figure 2. Die designs used in the case study, showing the front view and vertical cutaway-section (values in inches). The two die geometries vary only in their outer diameter (14 inches and 17 inches).

Numerical Results

Figure 3 provides a comparison of the predicted tool stress along the cutaway section for both the 14 inch and 17 inch diameter dies shown in Figure 2. The legs of the mandrel on the 14 inch diameter die may seem to have proper dimensions in order to address the accumulated plastic deformation; however, the central rib connecting the two cores of the mandrel shows a peak level of Von Mises stress that is significantly over the plasticity limit of 850 MPa (Figure 3-left). This is may lead to incipient cracks that are deleterious when extruding a hard alloy profile (such as AA7108) and might lead to mandrel failure after only tens of billets.

In the case of the 17 inch diameter die (Figure 3-right), the Von Mises stress is definitely shown to be lower. In particular, the central rib tips more than the legs, showing a significant reduction of the peak stress, which is

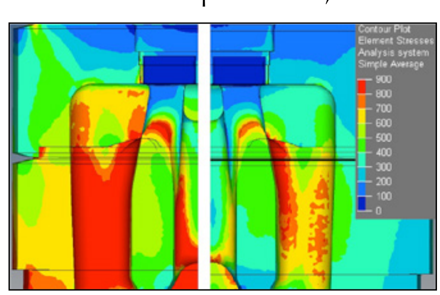

Figure 3. Numerical results for Von Mises stress (MPa) in the legs section of the 14 inch (left) and 17 inch (right) diameter dies. Extrusion direction is upward.

lower than the plasticity limit of the H11 tool steel. This is very promising in terms of a reduction of accumulated deformations and, therefore, will likely show increases in the life of the die.

The 17 inch diameter die also shows better numerical results in terms of deformation under load. Figure 4 illustrates that the mandrel of the 14 inch diameter die is expected to deflect more in the extrusion direction compared to the 17 inch diameter die. Numerical results show that a bigger die diameter offers more stability and therefore more consistent profile geometry during production.

Figure 5 shows the die deformation dynamic under load, which reveals that the external part of the mandrel holds back the legs and is deformed by the bending of the legs. If the port geometry is kept the same, then a thicker external part of the mandrel will act more like a "beam joint," thus reducing the displacement of the inner core part. Results also show that, due to the bigger surface contact between die and bolster, the press load is more uniformly transferred throughout the die and the bolster. Therefore, the bolster is less deformed at the contact, thus offering better support during extrusion.

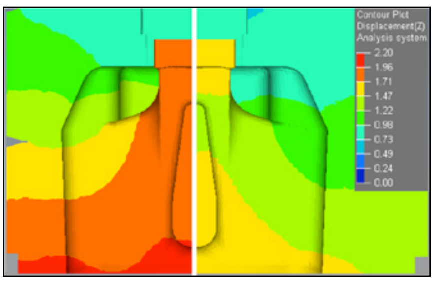

Figure 4. Numerical results for the mandrel displacement (values in millimeters) in the extrusion direction (upward). Choosing a wider die diameter (right) implies a reduction of mandrel deflection.

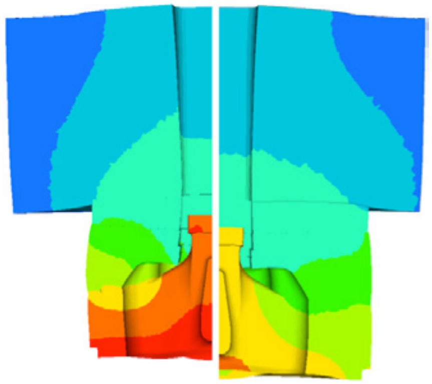

Figure 5. Magnification (50x) of the tool deformation under load in the extrusion direction (upward) for the 14 inch (left) and 17 inch (right) diameter dies. Picture shows the dynamics of the die and bolster deformation under load.

Conclusions

The choice of a bigger porthole die diameter can provide a significant reduction of mandrel displacement and stress under load compared to the smaller die. As a direct consequence, the adoption of a larger die diameter can provide higher extrusion recovery and increased tool operational life. While the latter can be partially offset by an increase in the purchase cost of the tool, the benefits of a more stable extrusion die are clear. Not only that, but a die with a bigger diameter can more uniformly transfer the load to the bolster, thus in turn being better supported. As a result, it is recommended that extruders choose a die diameter based on an engineering approach over a pricing one. ■

Tommaso Pinter *graduated in Industrial Engineering from Università di Trento nearly two decades ago and later studied metal forming processes at Bologna University. He is currently the CTO of Almax Mori & Alumat, an Italian networked organization of die vendors. He is the author of several aluminum industry publications. Contact Pinter at: www.linkedin.com/in/tommaso-pinter-460a8619.*