Recovery Assessment in the Extrusion of Aluminum Hollow Shapes

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Editor's Note: This article shows how extruders can minimize the front-end defect in aluminum porthole extrusions by utilizing finite element analysis (FEA) to design their dies to reduce scrap from the front-end defect without compromising overall press productivity. Front-end defects need to be removed from the extruded lengths in structural shapes made from higher strength 6xxx alloys, such as AA6061 and AA6082, which are commonly used in critical automotive applications, such as bumper beams and crash boxes and in profiles for rail carriages. Predicting the location of charge welds that comprise the front-end defect portion of an extrudate in porthole extrusion dies is one of the key elements of controlling recovery rates in extrusion plants, and extruders have employed time-consuming laboratory tests on cut-off front-end sections of extrusions when new dies are introduced into production. As described here, such a laborious assessment can be made in short time on the computer. Almax Mori & Alumat has conducted extensive experimental and computer trials to verify a FEM that correctly minimizes the front-end defect in a 6061 aluminum extrusion and studied this model for other aluminum alloys as well. They have successfully used the FEA approach on several hollow shapes. By combining FEA and their trademarked "butterfly die" design for hollow shapes (the latter reducing aluminum flow resistance without affecting mandrel stability), press productivity is increased while front-end defects are minimized.

Introduction

In designing porthole extrusions dies with high productivity rates, the geometry of legs and ports in the mandrel plate are critical. The mandrel geometry controls the strain and strain rate levels in extrusion, thus influencing the ram force for a given ram speed, stress on the legs, pressure in the weld chamber, temperature, and overall recovery rate. Using FEA capability, Almax Mori & Alumat have provided aluminum extruders with an accurate prediction of their scrap rate based on a front- and back-end defect determination for extruded hollows.

Almax Mori & Alumat are members of the Alumat Almax Group of Mori, Italy, which is the international group established for the design and manufacture of aluminium extrusion dies, made in Europe since 1966. Today, the group has a production capacity of 1,000 dies per month, made on specialized machining centers with integrated CAD-CAM systems (Figure 1).

Figure 1. Five-axis milling of an extrusion die at Alumax Mori & Alumat plant in Mori, Italy.

Back-End vs. Front-End Defects

Hot aluminum extrusion is a high productivity manufacturing process widely used for many different applications, ranging from civil and industrial engineering to furniture design and transportation sectors. Among the properties required of an extruded product are surface appearance, tight tolerances, and proper mechanical strength along the commercialized profile length, which is of crucial importance, especially in structural applications. Both extruded bar extremities should be tested, since these sections are potentially corrupted by defects that affect the final profile properties—on one extremity, billet skin contamination or back-end defect; on the other, the charge weld or front-end defect.

The back-end defect, or coring, results from the flow of the billet surface into the extrusion during the latter stages of the cycle. Ideally, this scrap is most efficiently incorporated in the butt or into the die. In practice, taking a butt of approximately 14% off the billet weight eliminates the back-end defect from entering the die.[1] While the butt length to avoid billet skin contamination can easily be determined, the location of the front-end (charge weld) defect needs to be verified, usually by etching the profile cross sections after the stop mark.

The charge welds, also called transverse welds, are generated when multiple billets are consecutively extruded one after the other to generate a continuous extruded profile. At the end of each process stroke, when a new billet is loaded into the press, the die is still filled by the material of the previous billet and their interaction produces a transition zone that extends to a variable length. The charge weld is usually contaminated by oxides, dust, or by lubricant applied during loading into the press. For this reason, the entire profile length affected by the charge weld has to be discarded because of its lower mechanical properties.

Industry Practice in Charge Weld Assessment

The exact position of the starting and ending point of charge welds is experimentally determined using laboratory analysis. The front-end of the extruded profile is analyzed by cutting several slices on the left side of the stop mark (Figure 2 – shown in red). Each specimen is usually ground and etched in Tucker's reagent on the same side with respect to the extrusion direction. The etching time is selected to achieve a good visualization of the macrostructure and varies between 20 to 60 seconds per slice. For each slice, the percentage area of the new billet is finally computed by means of CAD software after acquiring scanned high resolution pictures of the etched specimens.

A typical output result is shown in Figure 3, where the new billet advancement is marked by red. When the transition is complete, the profile is made of 100% new bil-

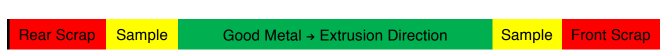
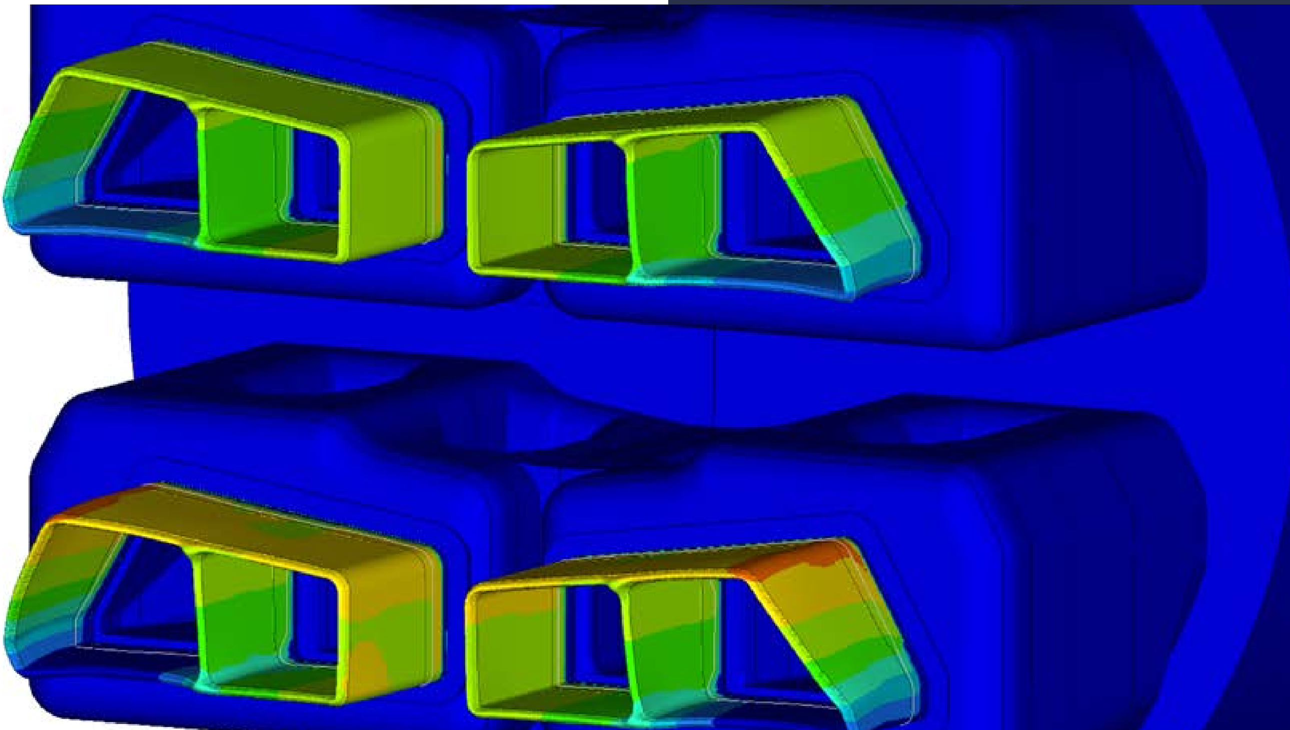


Figure 2. Schematic diagram used to experimentally identify coring and charge weld positions in extrusion.



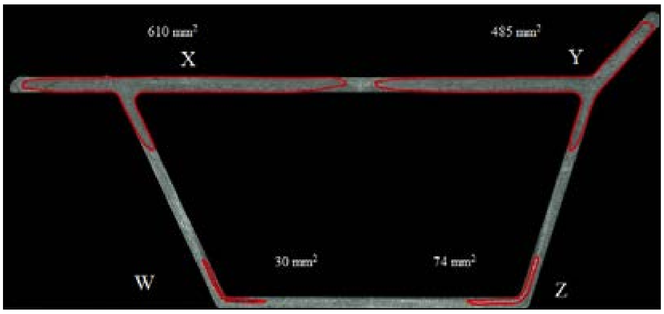


Figure 3. Experimental charge weld assessment on a 6061 profile slice by means of reverse engineering from a scanned picture.

let material, with the exact position of the start and end point of the charge welds having been determined experimentally. Laboratory experiments used to determine the charge weld portion are expensive, time-consuming, and their conclusions can be drawn only for a limited number of geometric configurations.

A breakthrough in the understanding and prediction of the charge weld phenomenon in hollow extrusions has resulted from the use of numerical approaches. In 2013, Reggiani and coworkers from the University of Bologna validated the capability of a commercial FE code to predict the charge weld extension for a complex 3D multi-hole porthole die, finding a good agreement between experimental and numerical data in terms of evolution of the phenomenon and dimensions of the segments to be discarded.[2] Then, in 2016, Pinter and coworkers showed that the empirical formulas presented in the literature are not suitable for predicting the extent of the front-end defect, while proposing that FEA should be used instead.[3]

State of the Art in Charge Weld Assessment

The evolution of charge welds in an extrusion is simulated at Almax Mori & Alumat by means of commercial FE codes used for the analysis and optimization of the extrusion process and dies, based on a fluid dynamic approach for modeling incompressible flows, including non-Newtonian fluid behavior. The computation of the charge weld evolution does not require simulations that are not included in the model. However, the heat exchange at the tool-billet interface is accounted for by setting proper values of the convective coefficients and reference temperatures.

The charge weld length calculation is performed by means of a transient analysis with moving boundaries. In this type of problem, the boundary conditions for the flow and heat transfer equations are treated as time-dependent, and the position of the billet back and of the billet-container interface are tracked during the simulation time. The mesh in the profile, bearing, porthole, and welding chamber remain fixed, but in the billet region the elements scale down linearly in the extrusion direction at each time step. The number of time steps is defined in a way to allow the estimation of the charge-weld extension with the required accuracy.

As an example, a commercial die was built to produce the profile shown in Figure 3, with the die ports designed to reduce the aluminum volume inside the portholes and so reduce the charge weld length. By FEA, it was possible to trace the transition between new (red) and old (blue) billets at four progressive times during the extrusion of the 6061 profile (Figure 4). FEA correctly predicted the replacement of the billet that first affected the thicker upper portion of the profile and then the thinner bottom.

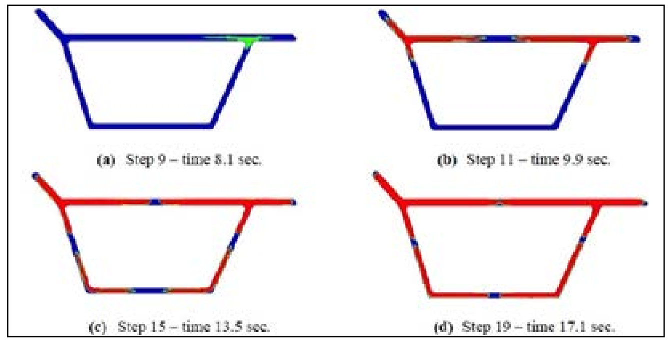


Figure 4. Evolution of the charge weld (transverse weld) formed at succeeding time steps during transition between new and old billets in extruding the shape shown in Figure 3.

Figure 5 shows a comparison of the percentage of the billet replacement over the stop mark distance as experimentally measured and numerically predicted for the profile in Figure 3.[3] As can be seen, a very good agreement is found between simulation and experiment, both in terms of charge weld length (starting and exhausting points) and general trend.

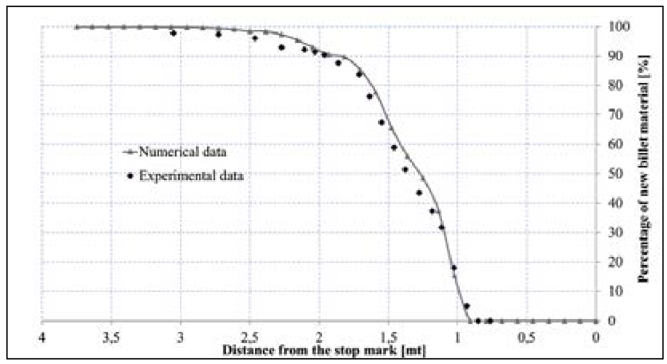


Figure 5. Comparison of experimental vs. numerical results for the percentage of new material over the stop mark distance for the extrusion of the structural profile shown in Figure 4.[3]

Figures 4 and 5 and the results obtained on several other profiles reveal that FEA is a precise and reliable technology for the assessment of the front-end defect in extrusion. Extrusion simulation is intensively used by Almax Mori & Alumat, considering that the engineering office performed 200 simulations during March 2017 alone. The FEA approach applies to all extruded alloys, except for the individual alloy input data in which constitutive equations relate strain, strain rate, and temperature to flow stress—parameters that affect extrusion pressure for a particular alloy throughout the extrusion cycle.[4] However, for a given porthole die design, the charge weld length and pattern numerically predicted by FEA is not affected by the main process parameters, such as ram speed and billet preheat temperature, nor by the extruded alloy.

An increase in requests have been seen coming especially from the automotive sector (bumpers and crash-box profiles) and from the high-speed train industry. As an example, Figure 6 shows a graphic representation in HyperView (Altair) of the billet interface evolution during extrusion of a large-scale structural hollow. Once the time frame at which the profile is entirely made of new billet material is determined, one can easily determine the charge weld extension.

Starting from a first assessment, Almax Mori & Alumat is capable of minimizing the charge weld extension by means of flow control at the design stage. A recovery factor increase up to 5% in the extrusion of hollow pro-

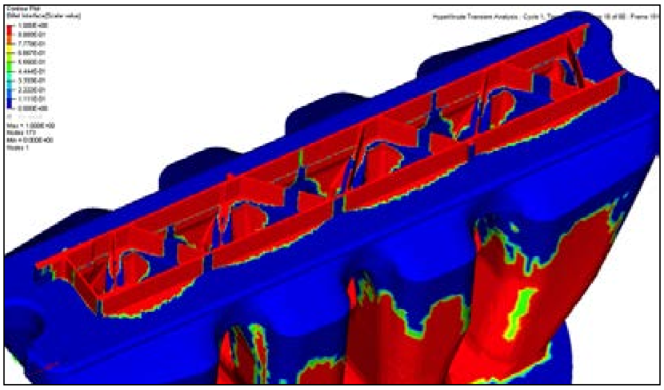


Figure 6. Example of a charge weld assessment by means of FEA using HyperXtrude (blue represents the old billet material and red the new material).

files can be achieved thanks to dead metal flow control using specially designed porthole dies with no dead zones (Figure 7).

Acknowledgments

The author would like to acknowledge the cooperation of Alexandria Industries and Altec Technologies for their assistance on gathering data regarding charge weld prediction and minimization.

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Figure 7. An example of a porthole die designed with dead metal flow control.

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