How to Understand and Counteract Snap Marks with Die Design and FEA

By Tommaso Pinter, Almax Mori

Editor's Note: Die-Related Extrusion Defects is an ongoing series dealing with the analysis of the defects encountered in extruded profiles that are related to the die design and its behavior under load. It will describe the physical origin of those defects including the ones related to poor mechanical properties and provides design practices to minimize them.

Introduction

This first article of the series focuses on extrusion defects that are often called snap marks. Extrusion defects are generated during the flow of aluminum in the billet container and throughout the die and should not be confused with scratches. During extrusion, the force on the tool stack exerted by the container gradually reduces along the push. This change in force increases die deflection from front to back. This occurrence becomes more significant in the case of large diameter dies (with liner sealing on the die) and in the case of thin profiles with poor support. Moreover, the thermal deformation of the die is subject to the same trend through the stroke, and therefore, snap marks are more likely to occur in the case of wide, hollow sections (see Extrusion Defects series by Jerome Fourmann, publishing in *Light Metal Age*, 2014-2018).

Typical best practices tell die makers and extruders to use either feeder rings or die sets with a feeder that are capable of adsorbing the stress from the billet, allowing the feeder to deform rather than the cap itself. The industry also recommends the adoption of full bolsters without spacers and to pre-heat them together with the die. Finally, pressure rings should also be periodically inspected in order to look for distortions.

The deflection of the die and the reciprocal sliding of its sections (Figure 1) can have a big influence on the wall thickness of the extrudate and may contribute to the appearance of the snap marks. In the case of dishing, typically the profile wall thickness becomes thinner and thinner until the snap mark occurs due to the sudden "stick-slip" event. After that, the wall thickness gets back to the previous value, thus generating a surface mark all along the section (Figure 2).

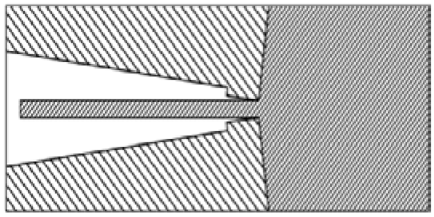

Figure 1. Rendering of cap deformation as a combination of dishing and deflection. Extrusion direction is toward the left.

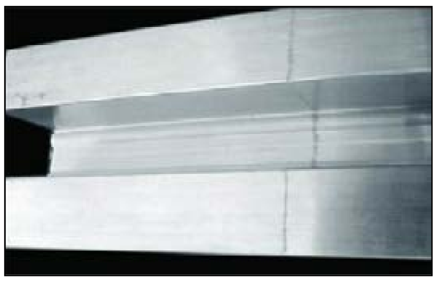

Figure 2. Snap marks on extruded aluminum profile shown at right angle to extrusion direction.

Die deflection cannot be avoided completely and can only be reduced. Therefore, attention should be dedicated to the reciprocal sliding of die pieces, using all the forces involved to allow a smooth cap dishing and/or to block the sliding as much as possible, based on an understanding of the dynamics of each individual die piece.

Case Study

The open section considered in the case study is a wide, flat shape typically subject to die dishing (Figure 3). As a consequence, it can be subject to a variation of the linear weight of the extrudate in respect of the nominal, as well as extrusion defects like snap marks. If the linear weight is under tolerance, the extruder is forced to require the die vendor to perform a modification using EDM wire erosion machining, because the dishing is usually stronger in the center of the die. Not only this, in the unlucky event of the appearance of snap marks, extruders face a tremendous reduction in the recovery. This last scenario is not good for the extrusion company, as it will result in a longer time to market than expected and detrimental additional costs.

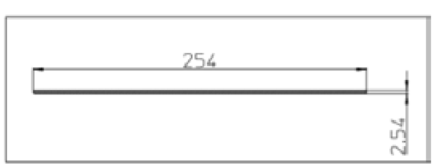

Figure 3. The AA6063 alloy extruded profile under investigation (values in millimeters). Such a thin and wide profile in regards to die diameter is the type of profile that is the most subject to die thermal deformation and cap dishing/deflection.

In this case study, the author quantitatively investigated the influence of widely adopted manufacturing practices on the behavior of the die under load with the aim of controlling the die dishing and deflection. Thus, the case study identifies a tool capable of extruding a profile with nominal wall thicknesses and without snap marks along the extrusion length.

Figure 4 shows the two die designs under investigation. In both designs, the three-set die is self-contained with feeder, cap, and backer and with a diameter of 16 inches and a thickness of 10 inches. Both dies were expected to be used on a 9 inch press with a liner sealing over the die, while a full bolster with a diameter of 16 inches and a thickness of 10 inches was considered for the support.

Design A is the benchmark die design (Figure 4a), in which the bearings opening at the front of the cap and four sealing pins were installed between the cap and backer with the aim of reducing the sliding of the cap over the backer. The feeder is left free to slide over the cap, and it is recom-

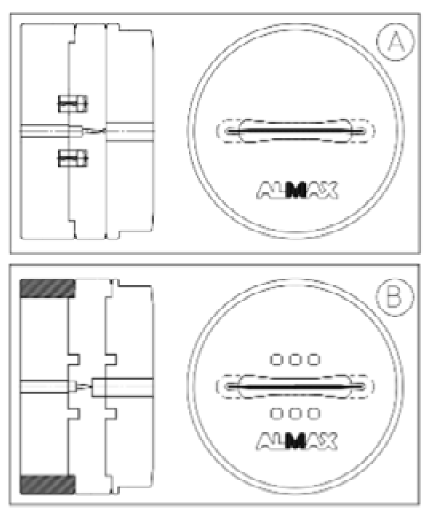

Figure 4. Die designs under investigation showing the front view and vertical cutaway-section. Design A is the benchmark, while Design B is the novel design considered after obtaining the results for the first design.

mended that extruders lubricate the contact surface, so the feeder will interfere as little as possible with the cap behavior.

Design B is the novel design, which was investigated following the results of the first die. This design features an integrated key in the cap and backer, bearings opening in the middle for the cap, and a shrinking ring applied to backer section.

The multidisciplinary simulation environment Altair SimLab™ was selected to accurately analyze the performance of the complex assemblies under investigation. All die sections, bolster and pins are supposed to be made of H11 steel and preheated at 470°C. The 3D models used for the simulations also included the bolster, while the pressure ring was treated as a rigid entity in order to reduce the number of nodes and therefore the computational time. Pressure and thermal loads come from transient flow simulations performed using HyperXtrude software.

Results for Design A

Figure 5 illustrates the numerical results in terms of cap dishing perpendicularly to the bearings for Design A. The picture shows a comparison of the vertical cap dishing (top) and a magnification of the cap deflection around the bearings region (bottom). Even though the dishing seems to be contained, the tendency of the cap to "close" due to the flow of aluminum is clear and a significant increase of this trend can be expected during the tool's operational life. Deflection

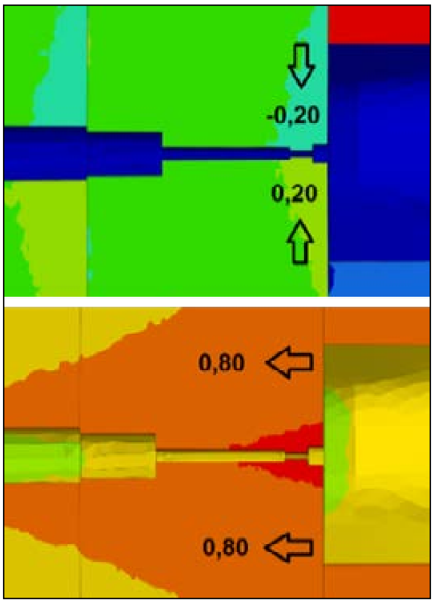

Figure 5 Cap dishing (top) and tool deflection (bottom) at the bearings region in the center of the profile for Design A (values in millimeters). Under load, the deformation of the cap for Design A might generate snap marks.

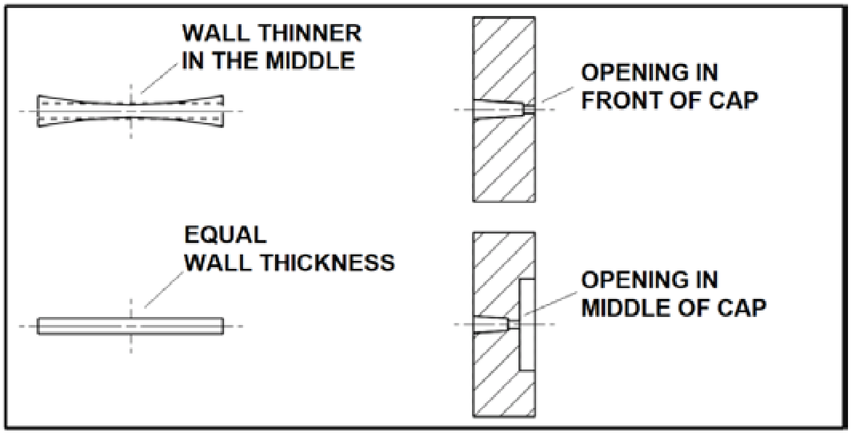

Figure 6. Rendering of the effect of different positions of the bearings in the middle of the cap in terms of wall thickness variation.

in the extrusion direction looks significant and its combination with the dishing might generate snap marks along the extruded section.

Results for Design B

Based on the first results, design B was investigated. The bearings region is moved in the direction of extrusion toward the center of the cap with the aim to obtain a uniform thermal deformation of the cap and reduce its dishing thanks to a deeper recess (Figure 6). Additionally, the cap section is connected with the feeder plate thanks to eight integral keys that will be more tightly connected with the feeder plate; this will help the aluminum pressure over the feeder internal walls to keep the cap open. Finally, a shrinking ring was applied to the backer with the aim of containing its deformation and therefore, reduce the sliding of the cap over the backer and the deflection of the tooling. Also, in this case, a full bolster with a diameter of 16 inches and a thickness of 10 inches was considered.

Figure 7 shows the numerical results for the optimized die design. The "tooth" keys are effective and allow the deformation of the feeder plate to keep the cap open; the result is a tool that, when under load, does not allow the cap to dish towards the center. Figure 7 also shows the significant reduction of the cap deflection in the extrusion direction due to the introduction of the shrinking ring around the backer. This die design will likely allow the extrusion of the profile section shown in Figure 3 with minimal die-related variations of the wall thickness along the push and therefore without snap marks.

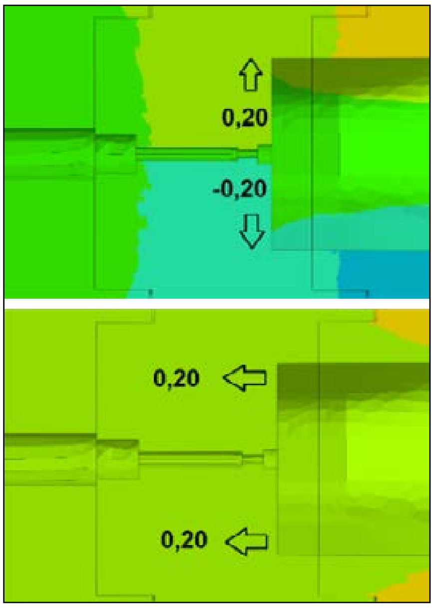

Figure 7. Cap dishing (top) and cap deflection (bottom) at the bearings region of the center of the profile for the novel Design B (values in millimeters). Dishing towards the center and deflection in the extrusion direction look inhibited and minimized respectively.

Conclusion

Using the right software, it is possible to describe in detail the thermo-mechanical behavior of an extrusion die made of different sections. Snap marks are related to the combination of dishing and deflection of the cap that, thanks to a rational design, can be minimized. Once the dynamics are understood, the die vendor can improve their die design and final dies, thus minimizing the die's contribution to extrusion defects. ■

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