Using Numerical Analysis of Coring and Charge Weld Defects for Scrap Assessment

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.

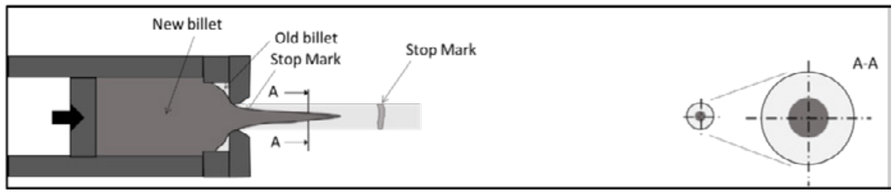

Figure 1. Schematic view of coring defect evolution for a solid bar.

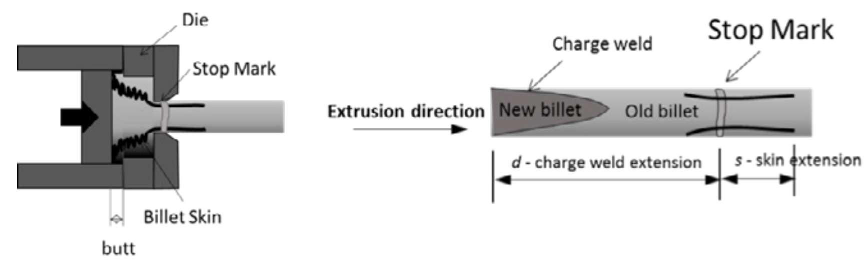

Figure 2. Schematic view of charge weld evolution for a round solid bar.

Introduction

Continuous direct extrusion is an economic and efficient process to manufacture high quality aluminum profiles. However, because multiple billets are being processed, transient defects—such as coring (known as billet skin or back end defect) and charge welds—can form, resulting in portions of the profiles being affected and deteriorating their mechanical properties. In the case of structural applications, the reliable prediction of the onset and extent of these affected portions is therefore mandatory in order to determine how much of the profile will need to be scrapped, while achieving the desired commercial length. This fifth article in the series examines the dynamic evolution of coring (Figure 1) and charge weld (Figure 2) defects in the continuous direct extrusion of an industrial solid profile.

Case Study

For the purposes of this case study, finite element (FE) numerical analysis was performed on a solid profile, and the results were evaluated in terms of coring and charge weld defects. In addition, the outcomes of analytical models available in literature were compared with the experimental results.

Figure 3 shows the geometry and dimensions of the AA6063 solid aluminum profile examined. The solid profile had a cross-sectional area of 599 mm^2 and an extrusion ratio of 46. The flat die used to produce the extrudate features two exits and is made of H13 steel. The tooling set includes a feeder plate in order to balance the metal flow and to allow for continuous extrusion.

The experimental production was carried out on an industrial 35 MN extrusion press and a transition between the fourth and the fifth extruded billets was selected to investigate the welding phenomena interaction in order to ensure stable conditions were achieved.

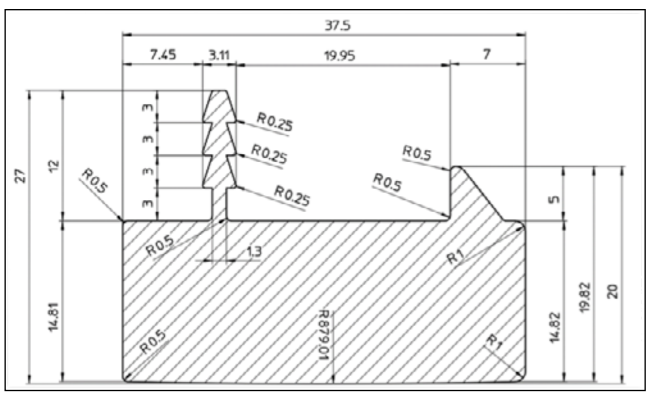

Figure 3. The solid profile being investigated (dimensions in mm).

Experimental Process

The front-end part of the extruded profile was analyzed by cutting 15 slices of around 100 mm each on the left side of the stop mark (back scrap) and 16 of the same length on the right side (front scrap). The central parts of the transition (520 mm of rear end and 130 mm of front end) were not available due to an operational problem during precision cutting.

Each specimen was ground and etched in sodium hydroxide solution, 20% in H_2O (250 g of NaOH for 1 liter of H_2O) on the same side with respect to the extrusion direction. The etching time was selected in order to achieve a good visualization of the defects and varied between 45 and 90 seconds per slice. The macrostructure of the defects was immediately visible to unaided eyes in the etched slices. For each slice, the percentage area of the new billet was computed by means of CAD software, after which scanned high-resolution pictures of the etched specimens were acquired.

In order to evaluate the billet skin layer thickness, a slice of one of the billets (taken from the same experimental batch) was initially collected. The specimen extracted was polished and etched to assess the microstructure of the billet surface. As can be seen in Figure 4, an inverse segregation zone of 250 μm depth contains contaminants and was then selected as the measurement of the skin. Figure 5 shows the experimental evolution of the charge weld and coring defects as monitored by the image analysis of 22 profile sections.

Numerical Analysis and Experimental Data

The flow behavior of the aluminum under the selected experimental conditions was simulated with the

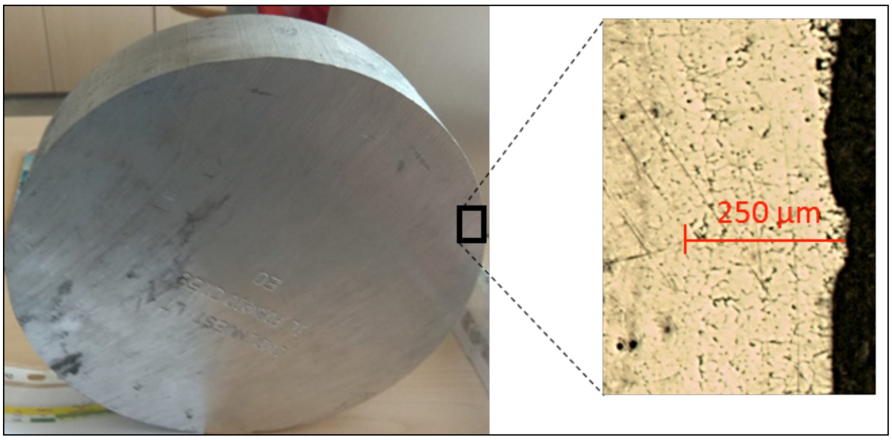

Figure 4. Billet skin layer thickness.

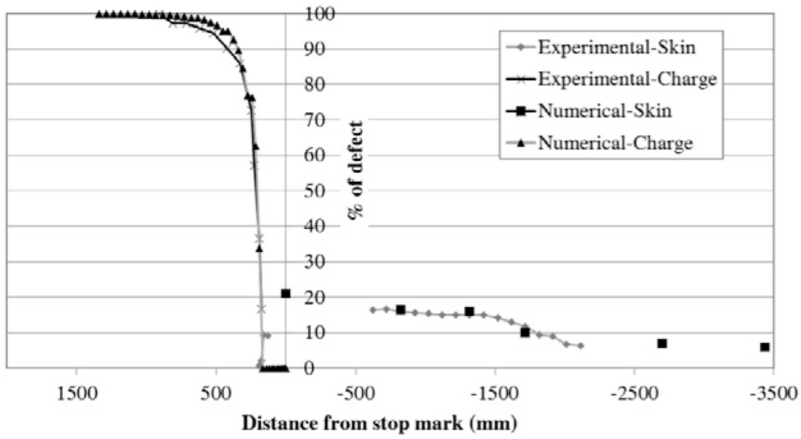

Figure 5. Comparison of the experimental vs. numerical percentage of the charge weld (left side, positive x-axis) and coring defect (right side, negative x-axis) over the stop mark distance for the investigated profile.

HyperXtrude® FE code. Calculations for the weld length and coring defect were performed separately by means of two transient analyses with moving boundaries. The flow behavior of the billet skin was predicted using the billet tracking function of the HyperXtrude software.

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 billet-container interface is tracked during the simulation time. The simulated mesh in the profile, bearing, porthole, and welding chamber remain fixed. However, in the billet region, the elements scale down linearly in the extrusion direction at each time step. A variable number of time steps was defined according to the experimental length of the cut slices. The total simulation time required to compute the charge weld and the coring defect evolution for the select profile was 233 minutes on a Linux CentOS multi-processor workstation.

If numerical data are compared to the experimental data that was acquired (Figure 5), it is possible to appreciate a good agreement on the overall trend in the case of the coring defect (right side) and a perfect match in the case of the charge weld evolution (left side).

Analytical Prediction

The experimental results were compared to formula reported in literature. For the analytical prediction of the charge weld extension, two formulas have been reported. The first equation was proposed by Saha in 2008,[1] as follows:

$$d = \frac{(V_1 + V_2)}{A_E \cdot n} \tag{1}$$

where V_1 and V_2 represent the total volume of metal left in the die port and weld chamber from the old billet, respectively; A_E the cross-sectional area of the extruded profile; and n the number of holes in the die.

The second formula is a modification of equation 1, introduced by Jowett, et al.,[2] in which a multiple factor of 1.5 has been introduced. The equation is represented as follows:

$$d = 1.5 \cdot \frac{(V_1 + V_2)}{A_E \cdot n} \tag{2}$$

The corrective factor of 1.5 accounts for the fact that the volume of metal that leaves the die at the start of next billet is less than the port volume—varying from 60-90% of the port volume due to the dead metal zones. The corrective factor also considers that the metal in the die does not leave as a simple plug, but moves faster in the center of the ports with a gradual clearing at the outside, suggesting a doubling of the prediction made with equation 1. The combined effect of these two contributions equates to about 150%, thus giving the 1.5 coefficient in equation 2.

As proved by Reggiani and Donati,[3] equation 1 provided no accurate estimation of the charge weld extension, while equation 2 returned a better agreement with experimental and numerical data. Thus, in the present work, only equation 2 was taken into consideration.

Concerning the coring (billet skin) defect extension, to the best of the author's knowledge, only a single analytical, empirical formula has been reported in literature. The equation used by Jowett, et al.,[2] for the prediction of the skin extension caused by the coring defect is as follows:

$$s = \frac{(14\% \cdot V_B - 75\% \cdot (V_1 + V_2) - V_{Butt})}{A_E \cdot n} \tag{3}$$

where V_B and V_{Butt} are the billet and the butt volume, respectively. As reported by Jowett, et al.,[2] 14% of the butt volume is what is typically considered to be coring scrap. This value is then reduced by the material that remains in the die volume (75% to exclude for the dead metal zones), which is expected to come out in the front end of the next extruded length prior to the charge weld and within the butt volume.

Table I shows the comparison between the experimental, numerical, and analytical results for both coring and charge weld defects. For the coring (billet skin) defect, experimental and numerical data have been compared at 1,717 mm, 1,318 mm, and 824 mm from the stop mark in the extrusion direction, achieving a very good agreement between the data as previously observed. The analytical equation 3 estimates the overall length of the skin-contaminated profile, the cut analysis was placed before the stop mark in the extrusion direction, so that the only available comparison would be with numerical predictions. For the specific case study in-

Defect Extension	Amount of Scrap	Experimental	Numerical	Analytical
Coring (skin) (*s* - extension)	1717 mm	15.50%	16.50%	—
	1318 mm	15.00%	16.00%	—
	824 mm	11.80%	10.00%	—
	Exhaustion	—	3,436 mm	3,317 mm (eq. 3)
Charge (*d* - extension)	—	909 mm	981 mm	361 mm (eq. 2)

Table I. Comparison of experimental, numerical, and analytical results for coring and charge weld defects.

vestigated, a very good match was obtained with an overestimation of the numerical data (of less than 3.5%) with respect to what was analytically computed.

For the charge weld, the experimental work carried out confirmed the numerical predictability of the defect with an experimental/numerical error of less than 8%. The analytical equation 2 returned a poor prediction, with an underestimation of the charge weld extension of 60%, when compared to the experimental data. This endorses what was previously reported by Saha on the requirement for novel analytical formulations that include more die geometrical factors and process parameters for a more accurate prediction of the charge weld length.[3]

Conclusion

A very good numerical and experimental agreement was achieved in terms of the general trend of charge weld, as well as its onset and exhausting point. A numerically predicted and measured length of the portion to be scrapped was determined to be 981 and 909 mm from the stop mark, respectively.

Concerning the coring (billet skin contamination), a good numerical experimental agreement was observed in terms of the general trend of coring defect, with a perfect match in the central part of the evolution. In addition, the comparison was satisfactory in terms of defect position within the profile section and of the overall shape.

The comparison of the numerical data with the analytical formulation reported in literature gave a poor predictability of the charge weld extension. However, a good predictability of the coring defect length before the stop mark was found, even if the comparison was possible only with numerical data.

References

1. Saha P., "Quality issues of hollow extrusions for aerospace applications," *Proc. of the 9th Extrusion Technology Seminar (ET '08)*, May 13-16, 2008.

2. Jowett, C., J. Adams, C. Daughetee, G. Lea, O.A. Huff, and N. Fossl, "Scrap allocation," *Proc. of the 9th Extrusion Technology Seminar (ET '08)*, May 13-16, 2008.

3. Reggiani, B. and L. Donati, "Experimental, numerical and analytical investigations on the charge weld evolution in extruded profiles," *Int. J. Advanced Manufacturing Technology*, Vol. 99, No. 5-8, 2018, pp. 1,379–1,387. ■

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