How to Predict Profile Front Scrap with a Novel Analytical Equation

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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 with the die design and its behavior under load. It will describe the physical origin of those defects, including those related to poor mechanical properties and provides design practices to minimize them.

Introduction

At the end of each process stroke, the back end of the old billet material that completely fills the die starts to interact with the front side of the new billet loaded into the press. This back end material is usually contaminated by oxides, dust, or lubricant, thus producing a transition zone that extends to a variable length. In the case of structural applications, it becomes clear that the length of the profile marked by the charge welds (called "front scrap") must be cut off and scrapped. Therefore, an accurate prediction of this portion of the profile becomes mandatory.

Several contributions to research and literature have proved that finite element analysis (FEA) is the most reliable approach to scrap prediction. However, FEA is seldom accessible to extrusion companies and, therefore, the industry is still looking for a valid alternative. This article discloses a new user-friendly equation for scrap prediction in direct aluminum extrusion that appeared in the proceedings of the ET '24 extrusion technology conference.

Numerical Prediction

The flow behavior of the aluminum was simulated with the finite element code HyperXtrude® by Altair Engineering. The weld length calculation was performed by means of transient analysis with moving boundaries. The total simulation time required to compute the charge weld and the coring defect evolution for each select profile was 180 minutes.

Analytical Prediction

Two formulas are reported in the literature (Saha and Jowet) for the analytical prediction of the charge weld extension. The one proposed by Jowet in 2008 is as follows:

$$d = 1.5 \cdot \frac{(V_1 + V_2)}{A_E \cdot n} \qquad \text{(Eq. 1)}$$

where V_1 and V_2 are the total volume of metal left in the die port and weld chamber from the old billet, respectively, A_E is the cross-sectional area of the extruded profile, n is the number of holes in the die, and *1.5* is a corrective factor that accounts for the fact that the volume of metal that leaves the die at the start of the next billet is less than the port volume. Eq. 1 provides accurate predictions only in cases of square and round pipes with uniform wall thickness, which are usually extruded using hollow dies with a few ports all having similar volume and significant dead metal zones.

Problems occur when the local extrusion ratio of each individual port varies significantly. In these cases, when the next billet is pushed, the aluminum already inside the die leaves each port at unequal times, thus generating a difference in the exhaustion of the charge weld among the ports. Some areas of the profile section are cleaned by the next billet earlier than others, as shown in Figure 1.

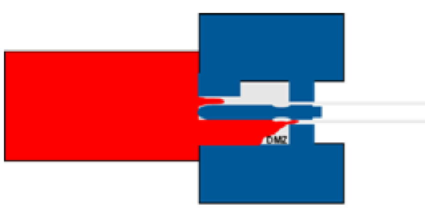

Figure 1. Graphical explanation of the charge weld dynamics. The blue area is the extrusion tool, grey is the aluminum in the die, and red is the new billet material getting into the ports.

Starting from these assumptions, it can be understood that the key to improving the existing equations is the adoption of a coefficient capable of describing the variation of the extrusion ratio among the different ports. At the same time, the equation should be user friendly without the need to access the CAD files of the die design that, in the majority of cases, are not fully available and would force the user to conduct time-consuming geometrical analysis. Finally, different corrective factors should be adopted to take into consideration the geometry of the ports and, indirectly, the profile shape.

The novel equation proposed by the authors of the ET '24 paper for the prediction of the charge weld extension (d) is as follows:

$$d = E_f \cdot C_f \cdot \frac{V}{A_E \cdot n}$$

$$E_f = \frac{A_{Pmax}}{A_{Pavg}} \qquad \text{(Eq. 2)}$$

where E_f is the extrusion factor, C_f is the corrective factor, V is the total volume of metal left in the die from the old billet, A_E is the cross-sectional area of the extruded profile, n is the number of holes in the die, A_{Pmax} is the cross-sectional area of the bigger port, and A_{Pavg} is the average cross-sectional area of ports feeding the shape measured at the die entrance after chamfers on mandrel bridges. For the corrective factor C_f, the authors propose the values in Table I.

Geometry	C_f
Standard Hollows	1.3
Pipes	1.5
No Dead Metal Zones Design	1
Butterfly Die™	1.1
Direct Central Feeding	1.6
Low Local Extrusion Ratio	2

Table I. The variable corrective factors proposed by the authors for Eq. 2.

Being the ratio between the biggest and the average port in term of cross-sectional area, E_f takes into consideration the different extrusion ratios among the ports, thus, increasing the charge weld extension in case the porthole die shows significant differences in the port areas for similar portions of profile section to be fed (e.g., rectangular pipes).

In this respect, it should be noticed that in the case of pipes, the novel Eq. 2 provides the same values as Eq. 1. In fact, the porthole dies used to extrude round and square pipes are designed with a certain number of ports having the same cross-sectional area and volume. In these cases, the introduced extrusion factor E_f becomes equal to 1.

However, E_f cannot describe complex profiles, and significant variations of the wall thickness can remove its own contribution or even work against it. For this reason, different values of the corrective factor become mandatory to reach a satisfactory predictability for Eq. 2. Although Table I shows the variations proposed by the authors, a skilled user can define their own values simply by comparing the scrap assessed in the laboratory or predicted by FEA with the one coming from the novel equation.

Last, but not least, the novel equation works using basic geometrical data (aluminum volume and ports cross-sectional area) that any die vendor shares on the die print. Therefore, the equation should be accessible to anyone in the industry and usable by unskilled users.

Results

Figure 2 shows a comparison between numerical and analytical results for all the 80 extrusions investigated by the authors in the ET '24 paper. The novel analytical equation returned quite a good prediction and the standard deviation looks satisfactory.

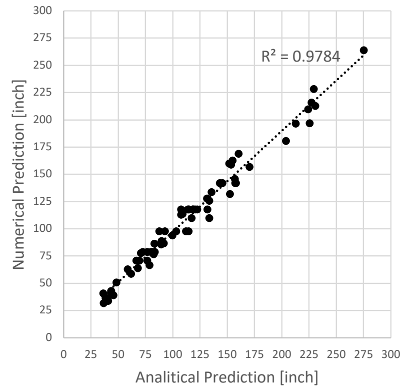

Figure 2. Comparison between the charge weld extension predicted by Eq. 2 and the values obtained with the numerical campaign.

Conclusion

In the original ET '24 paper, a comprehensive investigation was performed on hundreds of profiles. Transient FEAs have been run to simulate and capture the evolution of the back-end defect using the HyperXtrude code and the analytical models available in literature to predict and evaluate the defect.

Starting from an equation available in literature, a novel user-friendly analytical equation has been developed and optimized with the intention of providing the industry with a more accurate prediction of front scrap. Only basic geometrical information is required for the formula to work without requiring the CAD file of the die. A good numerical-analytical agreement was found in terms of charge weld extension. In detail, the new equation looks reliable and adaptable to different types of die designs and profile geometries. ■

Editor's Note: This article was adapted from the paper, "A Novel Analytical Equation for Front Scrap Allocation in Direct Aluminum Extrusion," by Tommaso Pinter, Barbara Reggiani, Riccardo Pelaccia, Lorenzo Donati, Marco Negozio, and Sarah Di Donato, which was presented at the 13th International Aluminum Extrusion Technology Seminar (ET '24). The modified version is reprinted here with permission from the Proceedings of the Thirteenth International Aluminum Extrusion Technology Seminar (ET '24), published by the ET Foundation and the Aluminum Extruders Council. All rights reserved. To obtain any papers from the ET '24 Proceedings, go to https://members.aec.org/store/viewproduct.aspx.