New Die Engineering Capabilities are Changing Extrusion Shape Feasibility

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Introduction

It is well known in the aluminum extrusion industry that the die plays a central role in being able to produce a certain extruded section, and consequently the contribution of the die vendor is becoming more and more important. During extrusion, the die is the tool most subject to severe stress. If the die is properly designed and manufactured, then extrusion of a given shape is possible—otherwise not.

Before the commercialization of finite element codes, design of extrusion dies was more a matter of "rule of thumb" than engineering. Even today, the majority of die vendors on the market are using the experience gained by their predecessors to design extrusion dies starting from the extrusion shape based on the supplied section print. In brief, it has been the experience of a die designer to define whether a certain section can be extruded by their customer and to extend a guarantee of performance.

Obviously, this approach can be a strong limitation to the development of new extruded shapes. It is easy to guarantee something that has worked in the past while, without die engineering, it can be extremely expensive and time consuming to find the limits of materials in extrusion and to meet or exceed them. It was only a few years ago that extruders were forced to order one or more dies and to perform several trials just to understand whether or not a new complex section could be supplied to the final user and to assess production costs.

A New Approach to Extrusion Shape Feasibility

A decade ago, Almax Mori in Mori, Italy, understood that the key to meeting the future requirements of our customers was to integrate our design offices with a technology capable of assisting them in the feasibility stage. In order to produce a die capable of extruding a section as is intended, it has been necessary to introduce finite element analysis (FEA). The current state-of-the-art of numerical simulations applied to the extrusion process by means of FEA has been exploited by an extrusion benchmark conference in various past editions.[1-2] As a result, a significant increase of FEA code accuracy was found in the prediction of aluminum extrusion process load, material flow, pressure, and temperature mapping. The engineering office in Mori participated several times at these extrusion benchmark conferences, so "FEA is in our DNA."

It has always been a practice for aluminum extrusion companies to ask the support of die vendors in the feasibility stage of deciding on an extrusion campaign, especially for the most complex sections. Before the commercialization of software codes for finite element modelling (FEM), which is the numerical technique used to perform FEA, empirical formulas based on experience have been used to evaluate the feasibility of die details (Figure 1), while

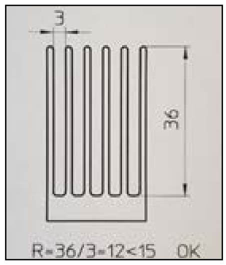

Figure 1. Traditional empirical approach to tongue ratio design.

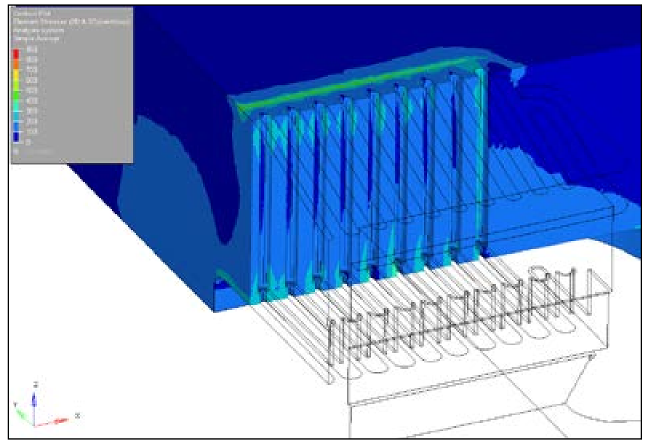

Figure 2. Stress analysis design by means of an elastoplastic model; today, the Von Mises stress, determined by FEA, is the critical factor affecting die performance.

today we are using FEA stress calculations based on an elastoplastic model (Figure 2). FEA stress calculations, giving a guarantee on critical tongue ratios, have shown that these are not just a matter of geometry but of aluminum flow as well. With this new approach, new limits can be reached without taking risks at the press and breaking expensive dies.

Extrusion Shape Feasibility and Lightweighting

According to CRU International, the current growth in aluminum extrusion demand is and will continue in the future to be driven mainly by the transportation market segment. Today, automotive and high-speed rail require lightweighting in order to use less energy to operate, and lightweighting means wider and thinner-wall extrusions. In order to supply recent rail projects, almost all the European players have been upgrading their big presses in order to overcome the lack in specific pressure to extrude the required sections. To meet the challenge, extrusion tooling should be properly designed to withstand the increased pressure required to extrude wider and lighter sections.

It is in respect to this challenge that the Mori engineering office has been organized in order to provide assistance with clear and precise data about the extrudability of new incoming sections for the fabrication of side walls, roofs, and floors for rail carriages. In order to succeed in this endeavor, the company commissioned several torsion tests at Italian research centers in order to have an appropriate constitutive equation for each aluminum alloy extruded.[3] This is probably the most important thing that distinguishes a successful extrusion simulation from another, because if the specific pressure required at the dummy block to press a billet out of a die is not correctly estimated, all the other results like temperature and pressure are meaningless. Thanks to the extrusion benchmark conferences, constitutive equations for various aluminum alloys are today available to the industry, despite the fact that many simulations are conducted using general equations available in the libraries of the FEM codes, thus often

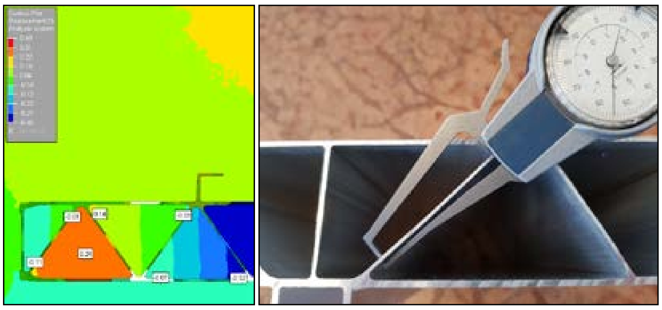

Figure 3. Prediction of mandrel displacement (vertical Y axis) in millimeters using an elastoplastic model (left). Dies that usually required correction at the vendor premises can be shipped overseas once it is verified that the wall thicknesses will be within tolerance, so that only minor corrections are required (right).

miscalculating the press force. The second most important thing in this respect is the knowledge of the process parameters in use at the press; the less assumptions one uses the better in terms of prediction accuracy when working with FEM codes. For this reason, cooperation between the process engineer at the extrusion company and the FEA engineer at the die vendor makes a difference.

Given a required rail section, the simulation department can understand not only if the aluminum flow will be balanced but also if the thickness of the inner walls will be within tolerance (Figure 3). This is mandatory especially in those cases in which the die is used overseas, as no returns should be required. The power of this approach lies in the fact that, for very complex profiles, it is possible to understand if the tolerances required by the final user can be reached during extrusion. Profiles that were not feasible before are today accepted as extrusions after die engineering—that's the revolution!

This is not all. Once the technological scrap at the extrusion line is known, the engineering office can provide extrusions with the required billet length in order to supply a certain section length and to verify if the press capacity is appropriate to overcome that specific billet length (Figure 4). In fact, thanks to a precise calculation of the front-end defect, the recovery factor can be estimated with enough accuracy to give full guarantee to the die performance, even from the point of view of the extrusion press capability (Figure 5).

The outstanding results achieved at Almax Mori are due to over ten years of hard and continuous improvement. That is why 10% of the working hours of our engineers are dedicated to R&D activities and to feedback from software houses with the appropriate data required to improve code performances, results accuracy, and new tool development. In 2018, we are committed to validate our in-house FEM code for the estimation of the back-end defect, while continually pushing software developers to implement better analytical models for the estimation of grain size variations due to dynamic recrystallization.

Conclusion

The engineering approach to extrusion profile feasibility is breaking away from the most common practices in the past. It is at the design stage of the aluminum section that the die vendor is now directly involved and not only at the commissioning stage. Today, extruders can know if a profile can be extruded and also accurately estimate the total scrap that could be produced before the die has been ordered. This gives a big advantage to the whole supply chain, significantly reducing both extrusion costs and time to market. By choosing the new design approach, extruders do not have surprises in terms of profitability once long term supply contracts have been signed because the recovery factor can be estimated with a good level of accuracy at the feasibility stage. Working in this way means reducing the gap between estimated production costs and effective production costs for extruders, thus beating their competition in what is increasingly a competitive and demanding transportation market. It is implied in this discussion that, even with this new approach, extruders will still have to deal with downstream operations to supply the requisite aluminum section—that is, the puller, water and/or air quenching, and aging can have a big influence in the production recovery of an extrusion line, even if temperature management and die construction are state of the art.

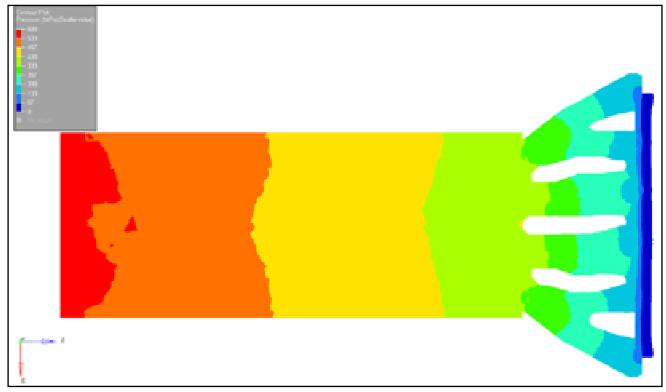

Figure 4. The press force required to extrude a defined billet length through the die is equal to the specific pressure at the dummy block times the container cross section area. In this case study the value is equal to 61 MN.

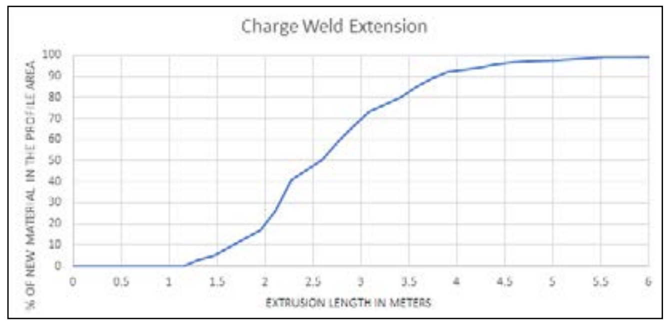

Figure 5. Example of the charge weld extension calculation by means of FEA, so that today the front-end defect can be known with high accuracy before the die is commissioned.

References

1. Donati, L., L. Tomesani, M. Schikorra, and A.E. Tekkaya, "Extrusion Benchmark 2007 – Benchmark Experiments: Study on Material Flow Extrusion of a Flat Die," *Key Engineering Materials*, Vol. 367, 2008, pp. 1-8.

2. Pietzka, D., N.B. Khalifa, L. Donati, L. Tomesani, and A.E. Tekkaya, "Extrusion Benchmark 2009-Experimental Analysis of Deflection in Extrusion Dies," *Key Engineering Materials*, Vol. 424, 2009, pp. 19-26.

3. Pinter, T. and M. El Mehtedi, "Constitutive Equations for Hot Extrusion of AA6005A, AA6063 and AA7020 Alloys," *Key Engineering Materials*, Vol. 491, 2012, pp. 43-50. ■

Tommaso Pinter graduated in Industrial Engineering at the Bologna University in Italy almost two decades ago where he studied metal forming. He is currently the chief technology officer of the Italian networked organization of die vendors Alumat & Almax. He is the author and co-author of several aluminum industry publications.