Digital Certification of Extrusion Dies Based on Simulation

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Introduction

Extrusion die sets are complicated and expensive mechanical tools. In many cases, a die's performance and the quality of the extruded profiles cannot be guaranteed unless they are tested in actual production. Even the most experienced die makers cannot envision all of the possible problems that may occur in a die during operation, regarding the product quality and die life span. In this sense, die design and manufacturing has traditionally relied more on experience than science. But now, reliable, accurate, and easy-to-implement extrusion simulation software has started to change the game. Extrusion simulation has become an indispensable tool for testing dies before they are manufactured or placed in the extrusion press.

Many die makers use QForm Extrusion software to simulate the process and virtually test a tool design to eliminate die corrections in an extrusion shop and to extend die life. Simulation allows for the estimation of the material flow, quality of the profile, die stress, and deflection, as well as the expected die life. Recently, with the implementation of QForm Extrusion Die Designer (QExDD), a new option has become available that allows for automated optimization of a prechamber shape and bearing design to achieve the most balanced material flow. Thus, recent developments in extrusion simulation and die optimization save time and costs by estimating the quality of newly designed dies before they are physically tested in production. Collaborating with many die makers and extruders, the company has concluded that such experience can be formalized as a checklist, where all die performance and quality aspects are verified and proven by numerical modeling. Going through the items of this checklist and answering its questions using simulations, the die designer will be able to analyze all vital aspects of the die's performance. When it is completed, this checklist will be considered an Extrusion Die Digital Certificate (ExDDC) that can be passed from the die maker to an extruder to prove the quality of the die in terms of its performance and die life estimation.

Extrusion Simulation

As shown by numerous industrial experiments and specially organized benchmark tests,[1] the most accurate results of extrusion simulation can be provided by an integrated approach that couples the material flow with the deformation and temperature of the tool in a die set. This means that the elastic deformation of the die influences the material flow, while the die distortion itself is dependent on the contact pressure applied by the deformed material.[2] This coupled solution is obtained through several iterations combined with automated remeshing of the flow domain.

With this method, the most accurate results in the material flow, profile shape, and temperature in the billet, die, and profile can be achieved (Figure 1). In the case of taper heating of the billet, the initial temperature gradient is also taken into account. The solution shows the possible distortion of the profile shape and variation in thickness, which may be significantly different from what is expected due to elastic deformation of the die orifice. Thus, a coupled simulation allows the die maker to modify the die design in order to compensate for the elastic deformation of the die, keeping the finished profile geometry within tolerances (Figure 2).

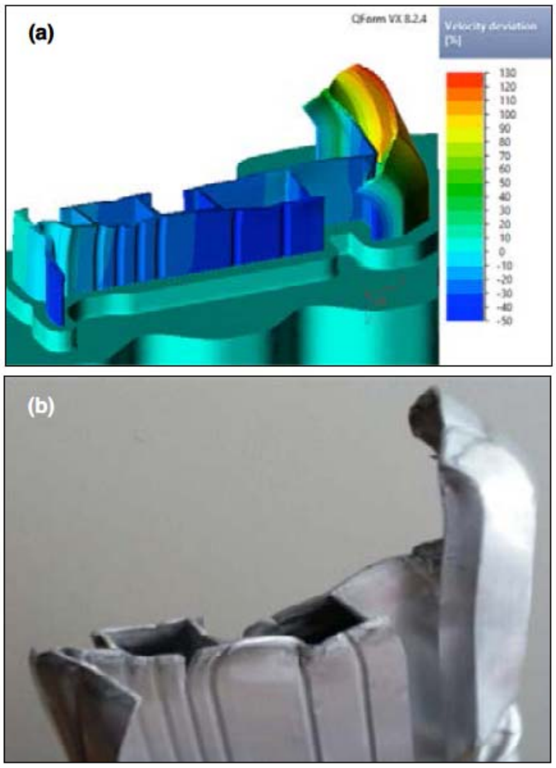

Figure 1. Simulation of a complex hollow profile, showing the relative velocity of deviation distribution (in percent) and the profile front tip shape obtained in simulation (a) and the actual front tip after extrusion (b).

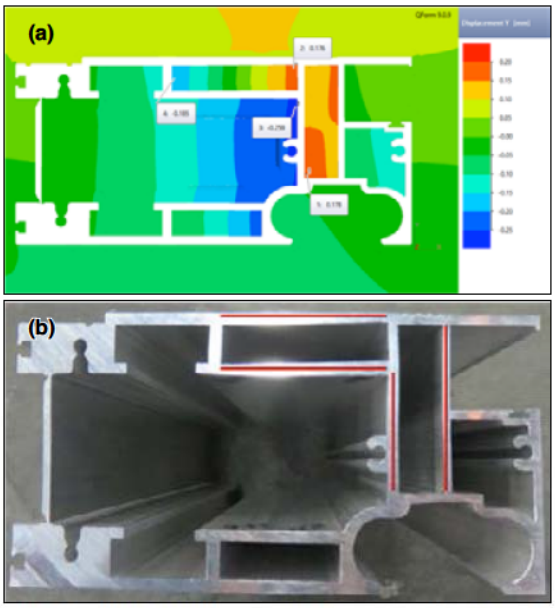

Figure 2. The effect of displacement of components in the extrusion die in Y direction, showing the simulation result (a) and the actual profile crosscut (b).

The next important profile quality parameter is the position and strength of seam welds. A simulation accurately predicts seam weld positions, and the die designer can change their location by modifying the shape of the feeding channels. Seam weld strength is dependent on the length of the welding chamber, the pressure and temperature of the material in it, as well as the extrusion speed, so the simulation allows analysis of all these parameters to achieve the best welding quality.[3] Another critical parameter of the profile quality estimation is the possible existence of non-filled zones in the profile body (Figure 3).

Die life depends on the stress state and temperature during an extrusion process. As a result of simulation, the criteria of the die life estimation can be determined, including stress triaxiality, location of plastic deformation zones, and overall die deformation.

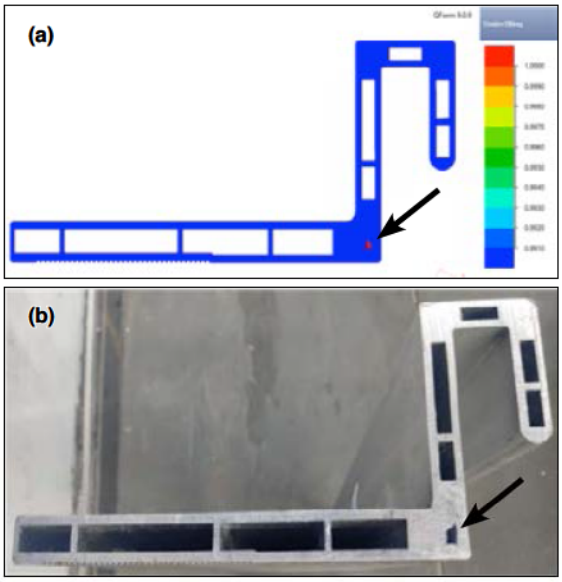

Figure 3. Location of the non-filled zone (hole) of the profile, showing the simulation prediction (a) and the actual hole location (b), which is indicated by an arrow.

Digital Certification of an Extrusion Die

When developing a design, a die maker usually makes several alterations to the die geometry regarding the portholes shapes and location, bridges, welding chamber, prechamber, and bearing. After each alteration, the manufacturer checks the efficiency of these changes through simulation.[4] The summary of simulation results of the final variant of the die design can be formalized in the ExDDC, which includes:

- The drawing of the profile.
- The geometry of the die set that has been manufactured and delivered.
- Complete list of technological parameters for which the die simulation has been performed.
- The material flow analysis results (velocity deviation and profile distortion).
- Extruded profile quality estimation (seam weld quality and location, charge weld propagation, under filling, and streaking lines).
- Die stress and deformation analysis and die life estimation (deformed die orifice, plastic zones in tools, tension triaxiality, and die temperature).
- Summary of the overall die performance estimation and remarks/recommendations.

All this information is accumulated in a single electronic document where drawings and simulation results (as bitmaps and graphs, etc.) are presented. Thus, the overall die performance estimation is formulated as a final verdict of the die performance (Table I).

#	Check-Position	Acceptance
1	Profile flow uniformity	(Yes/No)
2	XY displacement in tools	(Yes/No)
3	Plastic zones in tools	(Yes/No)
4	Tension triaxiality	(Yes/No)
6	Profile temperature	(Yes/No)
7	Deformed die orifice and tolerances	(Yes/No)
8	Charge weld propagation	(Yes/No)
9	Welding seams location	(Yes/No)
10	Welding seams quality	(Yes/No)
11	Profile filling	(Yes/No)
Overall Verdict: Is the die acceptable?		**(Yes/No)**

Table I. Overall die performance checklist.

Gains for Die Makers: Filling in an ExDDC form, a die maker systematically goes through all aspects of a die's performance in the extrusion process before actual extrusion is performed and even before the die is manufactured. Such practice saves time and money by avoiding errors and missing essential parameters, as well as increasing overall product quality and profitability. Delivery of consistently error free dies boosts the manufacturer's reputation.

Gains for Extruders: Obtaining a die supplied with ExDDC, an extruder has more confidence in a new die's performance. It can be easier to see the die's potential limitations and possible drawbacks, which can then be minimized through proper selection of extrusion parameters.

As an advanced option, an ExDDC can be supplied with a simulation model of the die created by a die maker. Thus, if necessary, an extruder will be able to run the simulation themselves and test the die performance for some process conditions that may be of particular interest according to the specific production environment and equipment conditions. For example, this type of on-site modeling can be helpful to check how increasing extrusion speed may influence the product quality in terms geometrical accuracy and properties, as well as the temperature of the die and its life span, etc. An extruder's usage of a simulation model already created by the die maker saves time and money by avoiding unnecessary extrusion trials.

References

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4. Biba, N., S. Stebunov, and A. Lishnij, "Automated Extrusion Die Design Integrated with Simulation," *Proceedings of the Eleventh International Aluminum Extrusion Technology Seminar (ET '16)*, Vol. 1, May 2016, pp. 591-602. ■